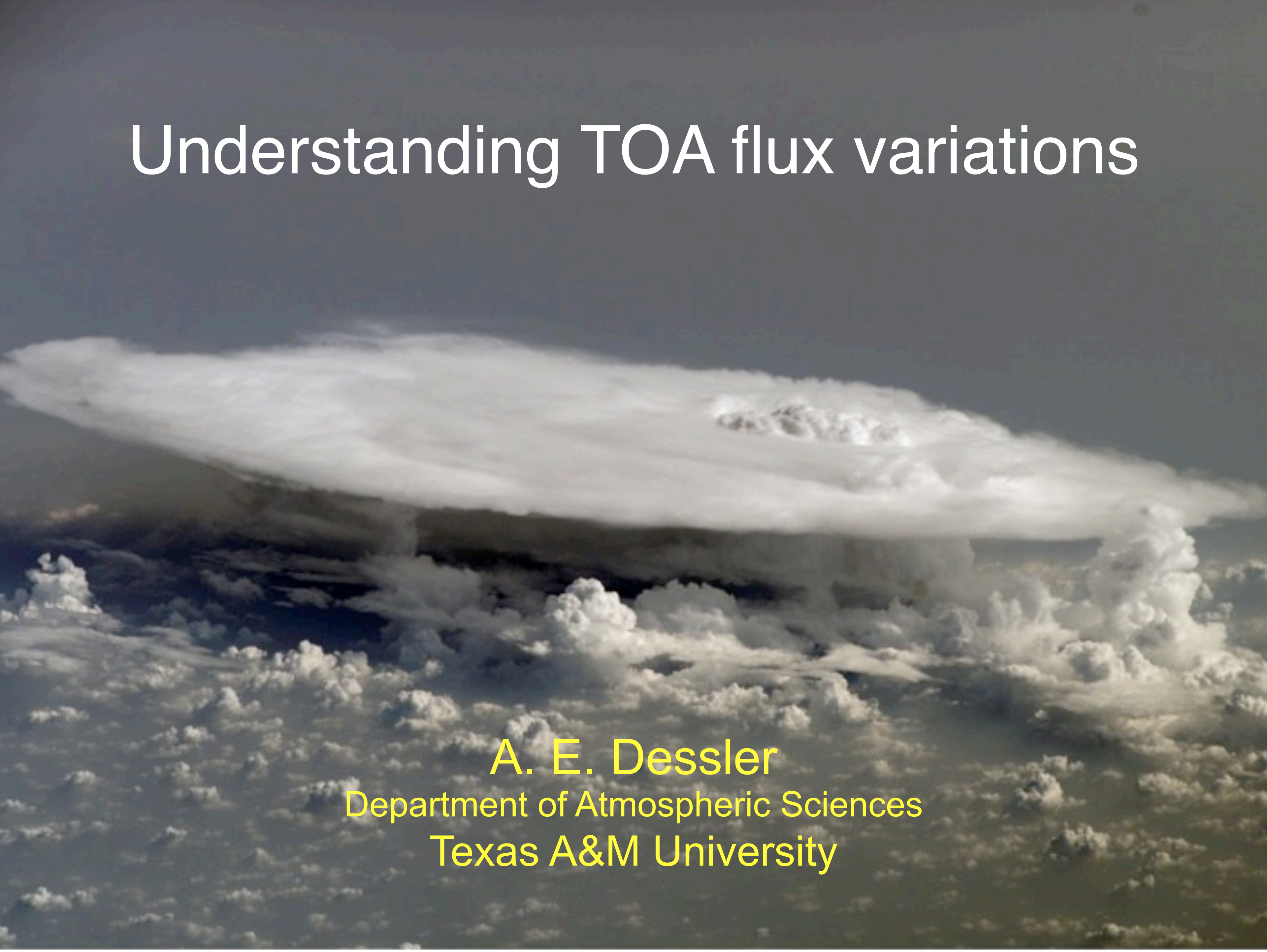
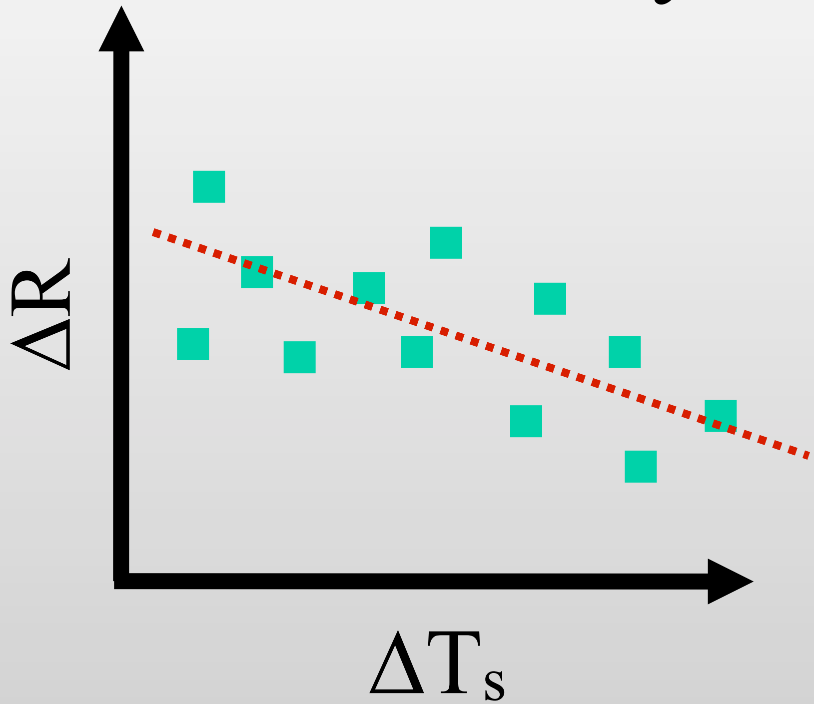
Understanding TOA flux variations



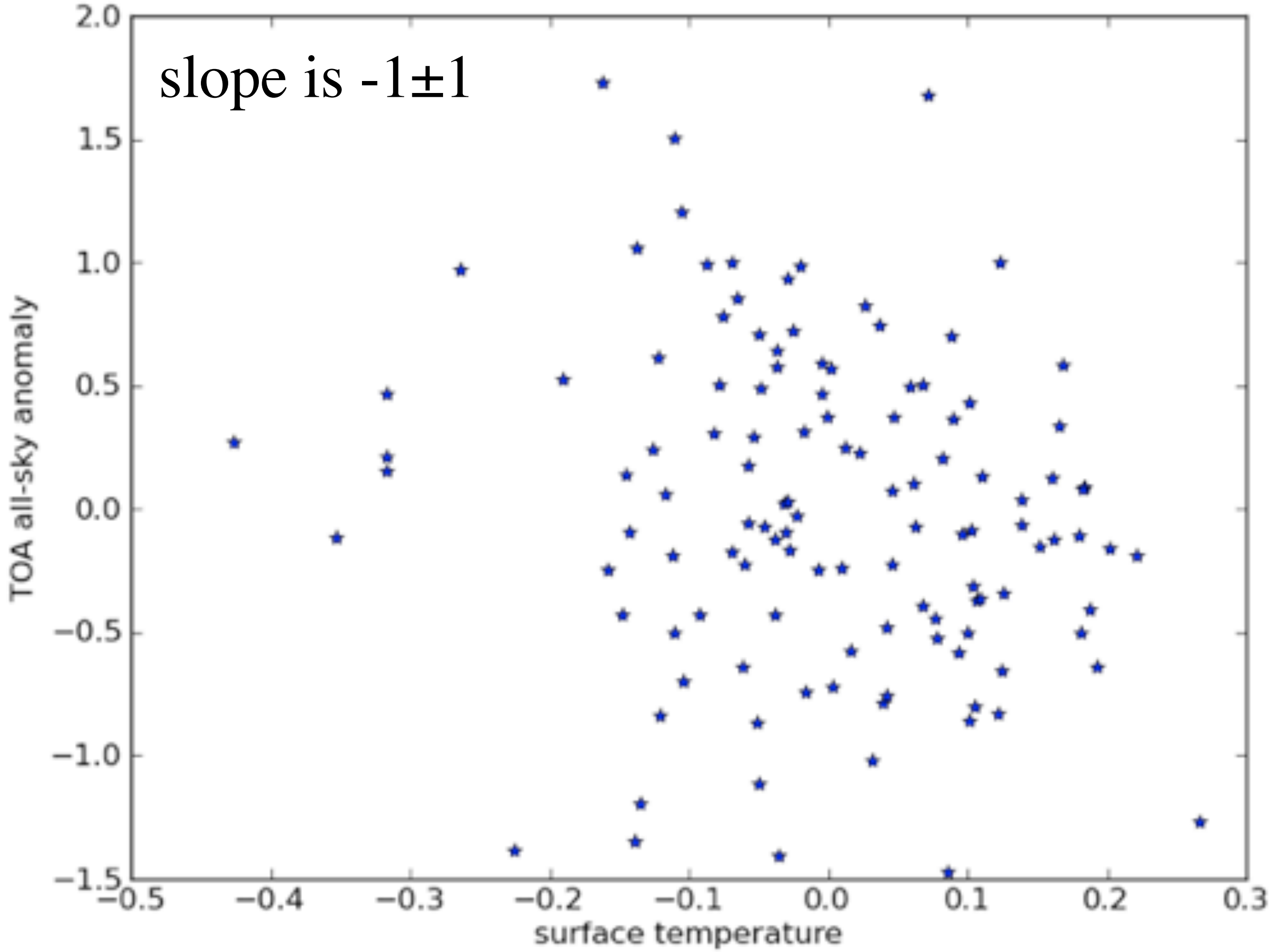
A. E. Dessler
Department of Atmospheric Sciences
Texas A&M University

... to better understand climate sensitivity



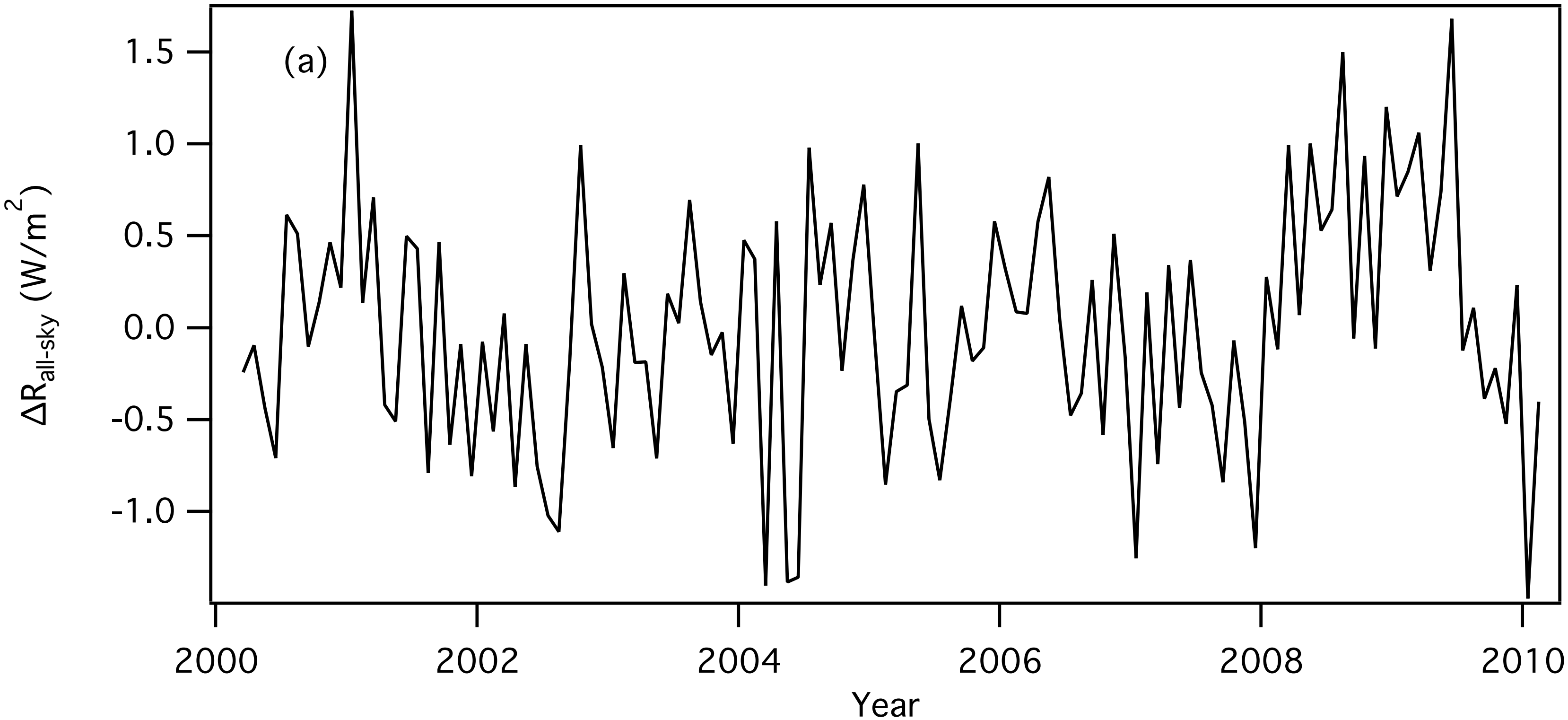
e.g., Forster and Gregory, 2006;
Lin et al., JQSRT, 2010; Murphy, 2010

all fluxes in this analysis are downward positive



slope is -1±1
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−0.5
−0.4
−0.3
−0.2
−0.1
0.0
0.1
0.2
0.3
TOA all-sky anomaly
surface temperature

CERES top-of-atmosphere (TOA) net flux
SSF, 1-deg monthly avg., Ed. 2.5



all fluxes in this analysis are downward positive

$$\Delta R_q = \sum_{x,y,z} \frac{\partial R}{\partial q(x,y,z)} \Delta q(x,y,z)$$

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water vapor anomaly

$$\Delta R_q = \sum_{x,y,z} \boxed{\frac{\partial R}{\partial q(x,y,z)}} \Delta q(x,y,z)$$

water vapor anomaly

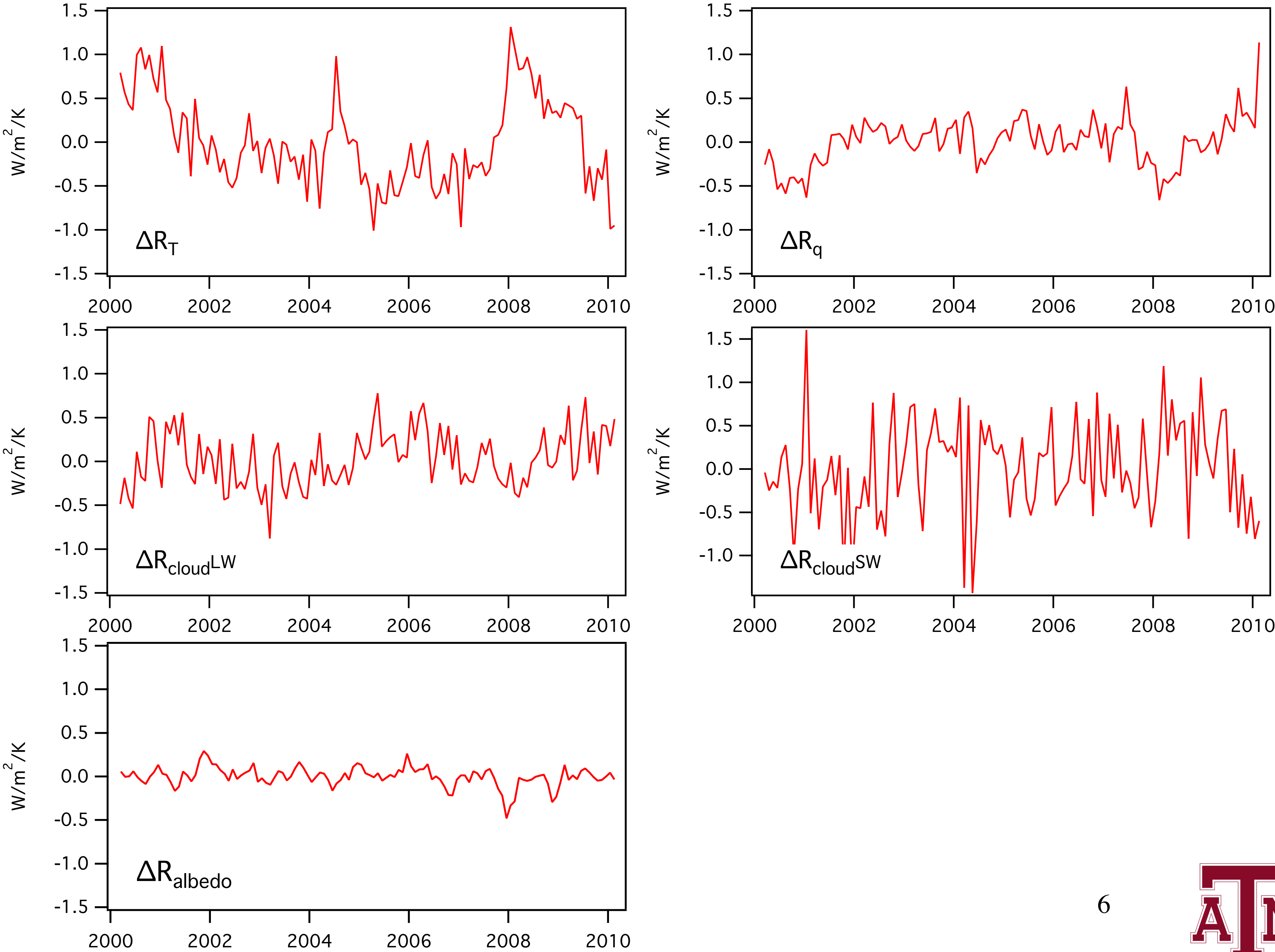
Use pre-computed kernels from Soden et al., 2008, see also Shell et al. [2008]

$$\Delta R_q = \sum_{x,y,z} \boxed{\frac{\partial R}{\partial q(x,y,z)}} \Delta q(x,y,z)$$

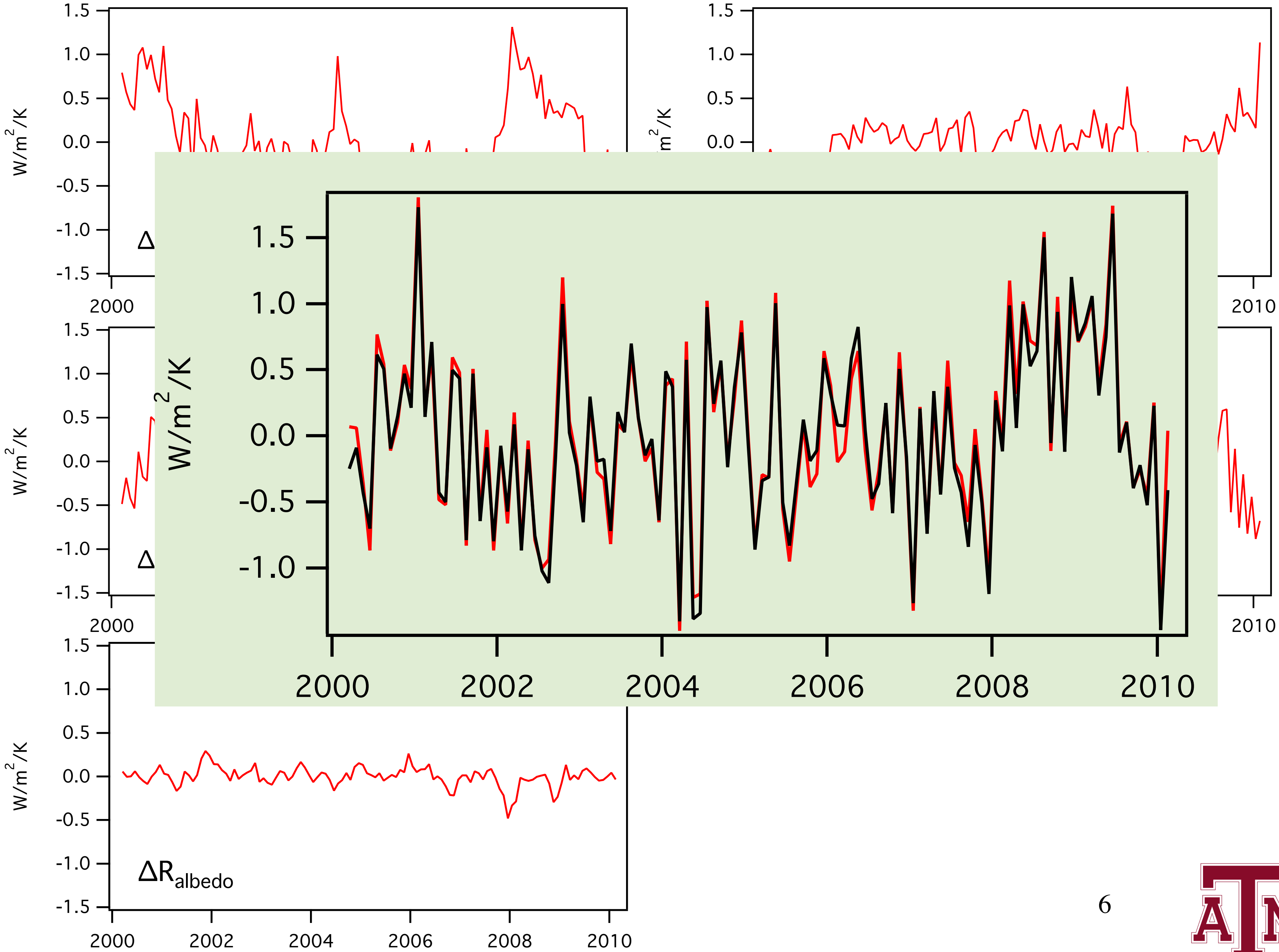
water vapor anomaly

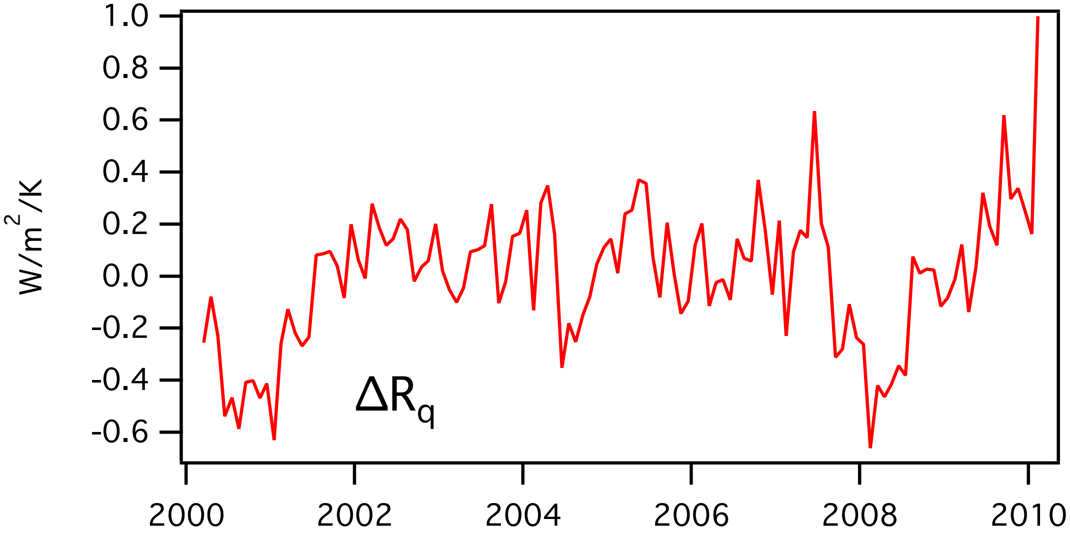
Use pre-computed kernels from Soden et al., 2008, see also Shell et al. [2008]

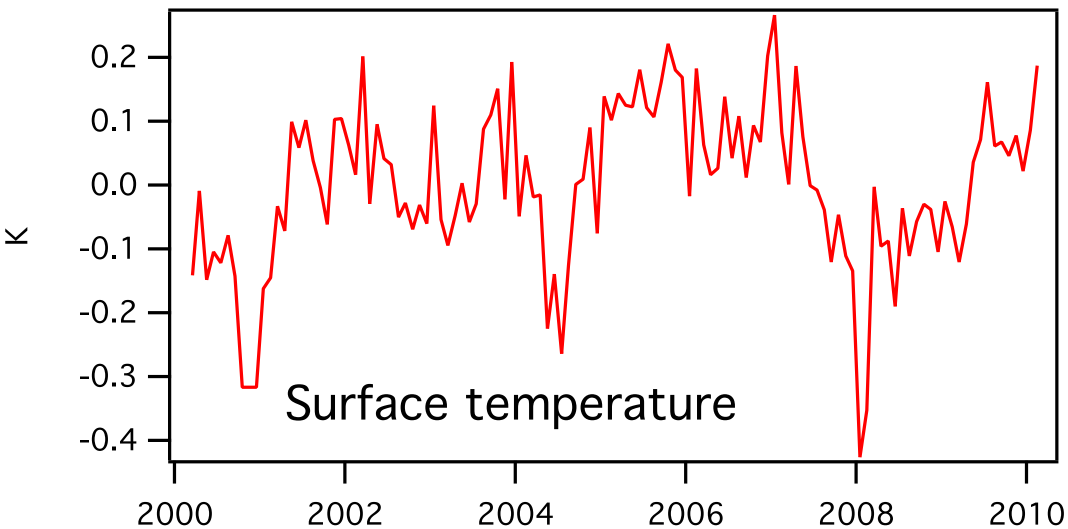
$$\Delta R_T = \sum_{x,y,z} \frac{\partial R}{\partial T(x,y,z)} \Delta T(x,y,z)$$



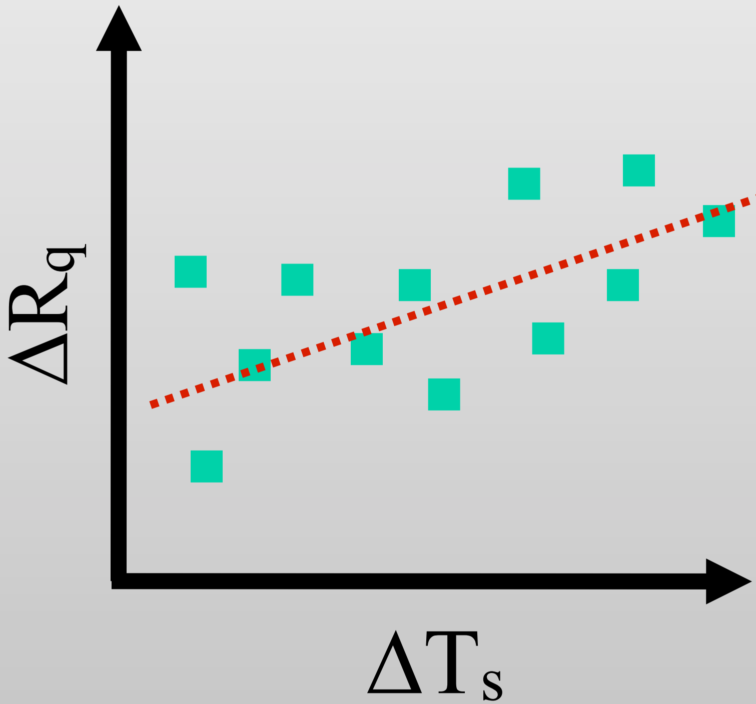
ΔR_T
ΔR_q
ΔR_cloud LW
ΔR_cloud SW
ΔR_albedo
W/m^2/K
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
2000
2002
2004
2006
2008
2010

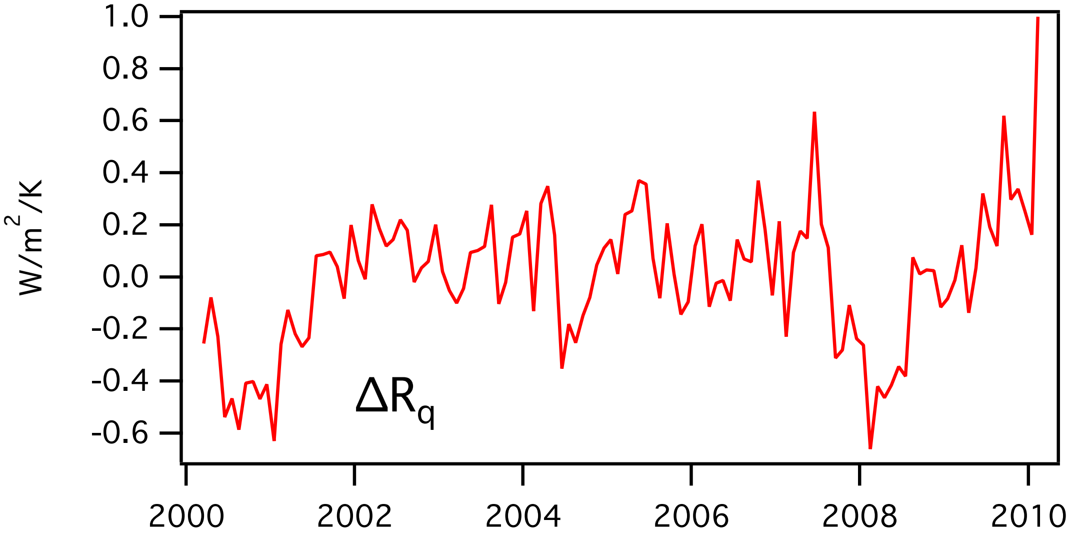

W/m2/K
1.5
1.0
0.5
0.0
-0.5
-1.0
2000
2002
2004
2006
2008
2010
ΔRalbedo

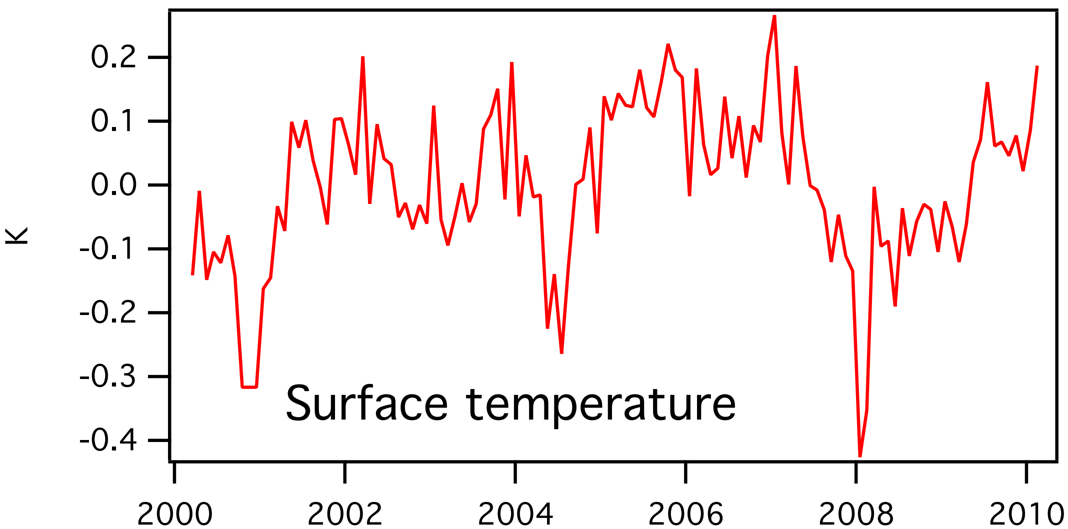

1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
W/m2/K
ΔRq
2000
2002
2004
2006
2008
2010


0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
K
Surface temperature
2000
2002
2004
2006
2008
2010

Regress energy trapped by e.g., q vs. surface temperature

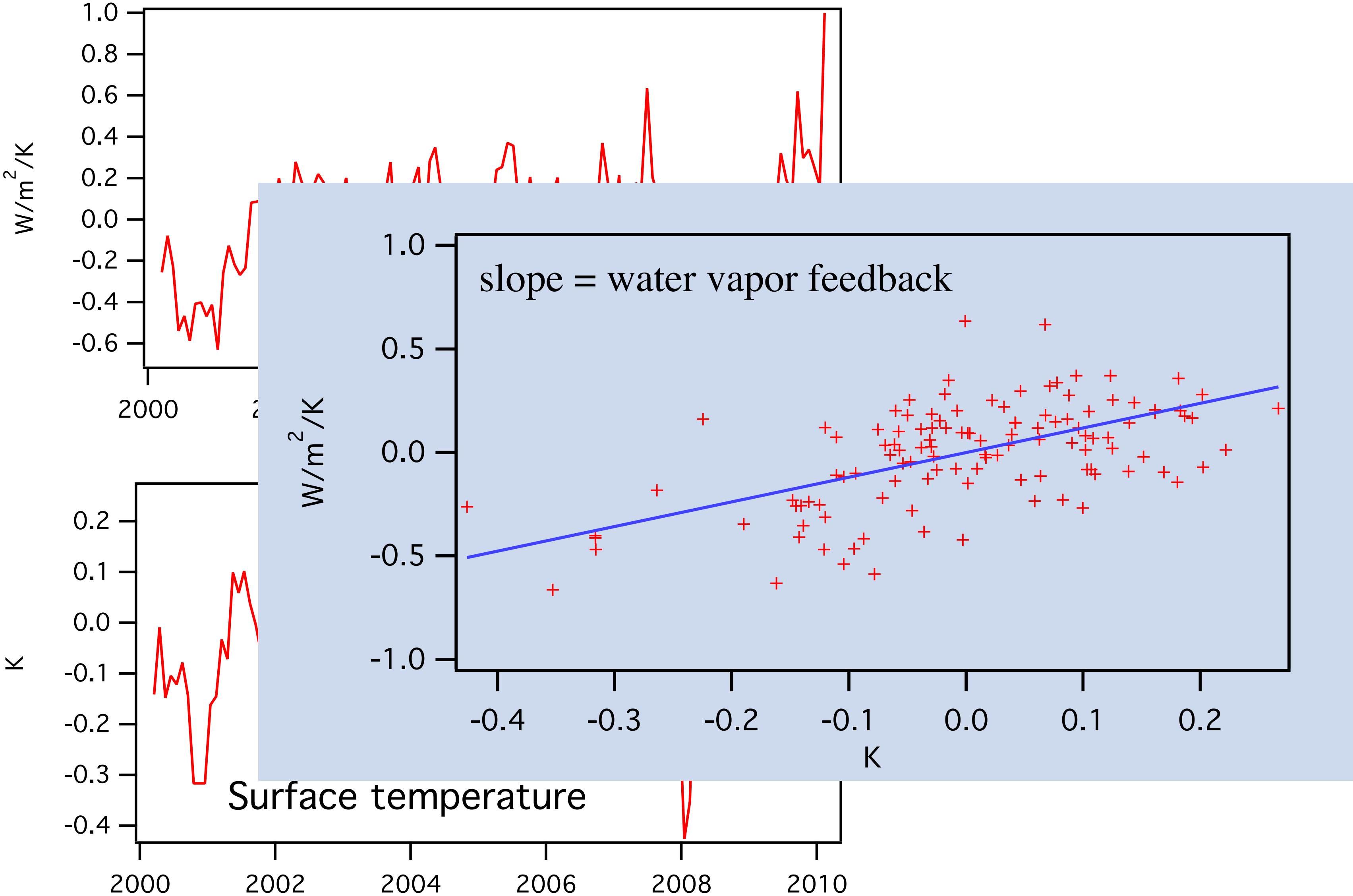






Dessler et al., GRL, 2008

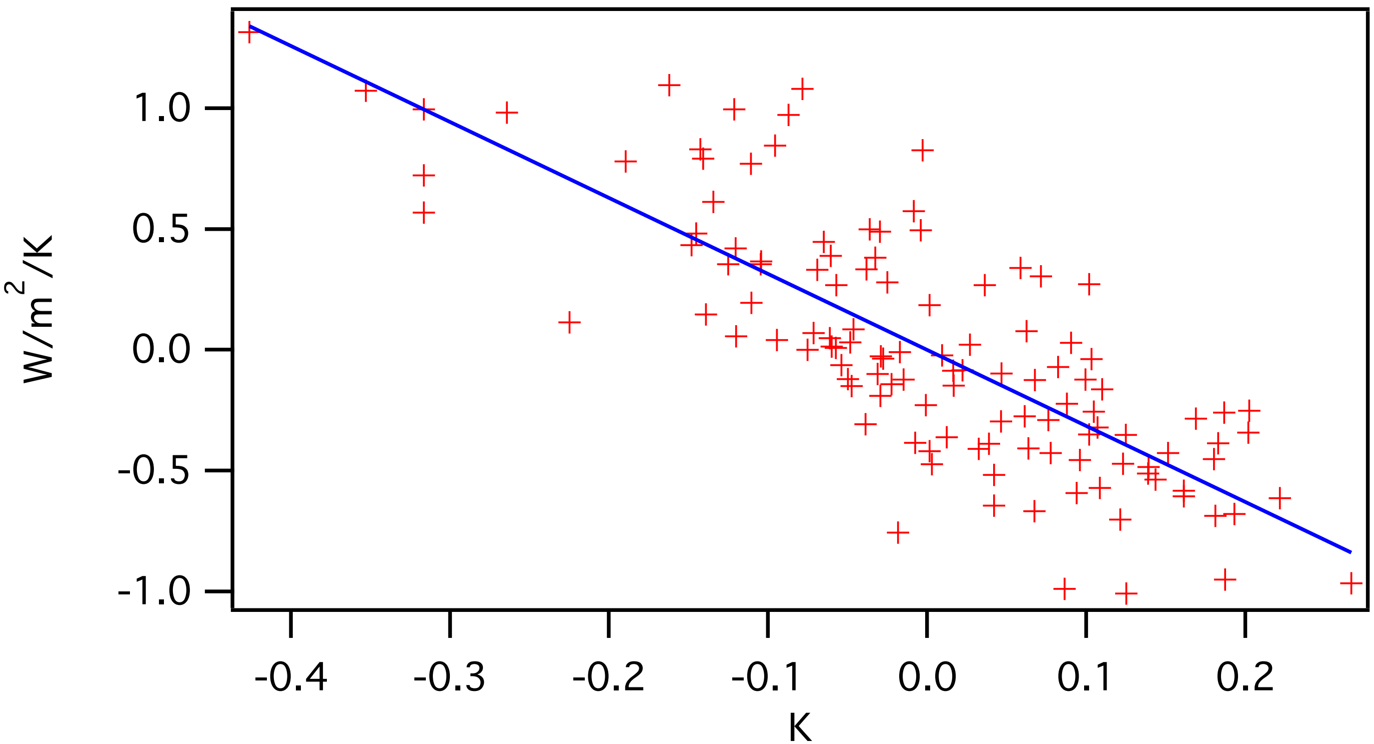
Dessler and Wong, J. Clim., 2009



Dessler et al., GRL, 2008

Dessler and Wong, J. Clim., 2009

Temperature feedback



albedo feedback

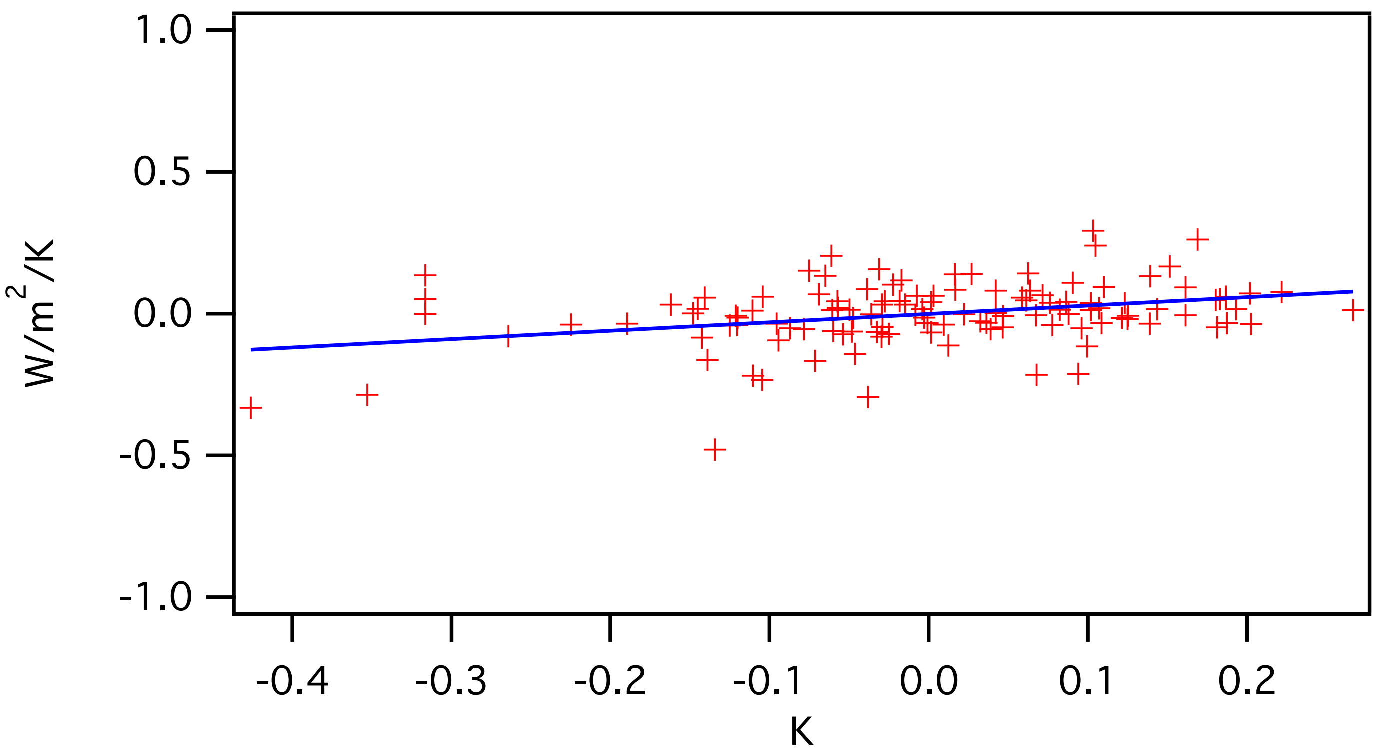
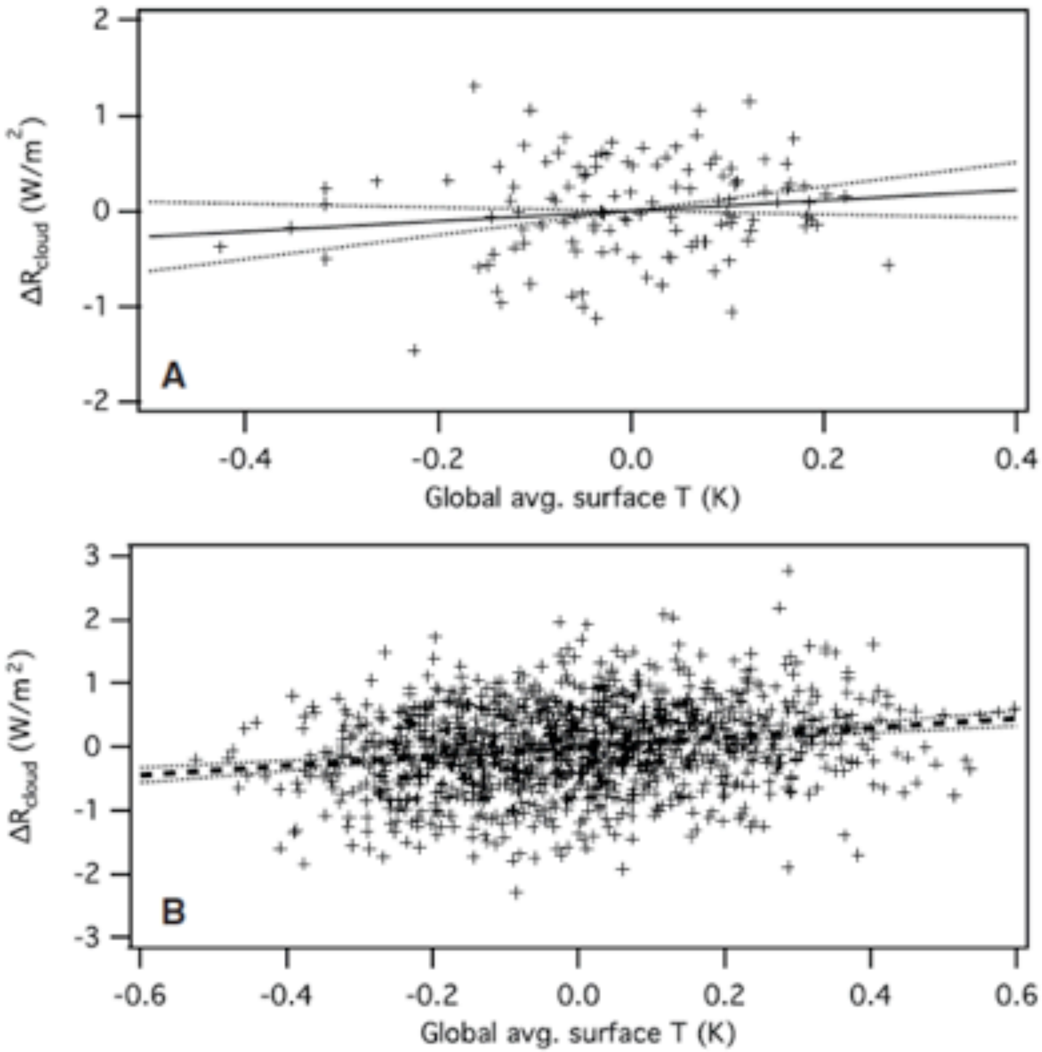
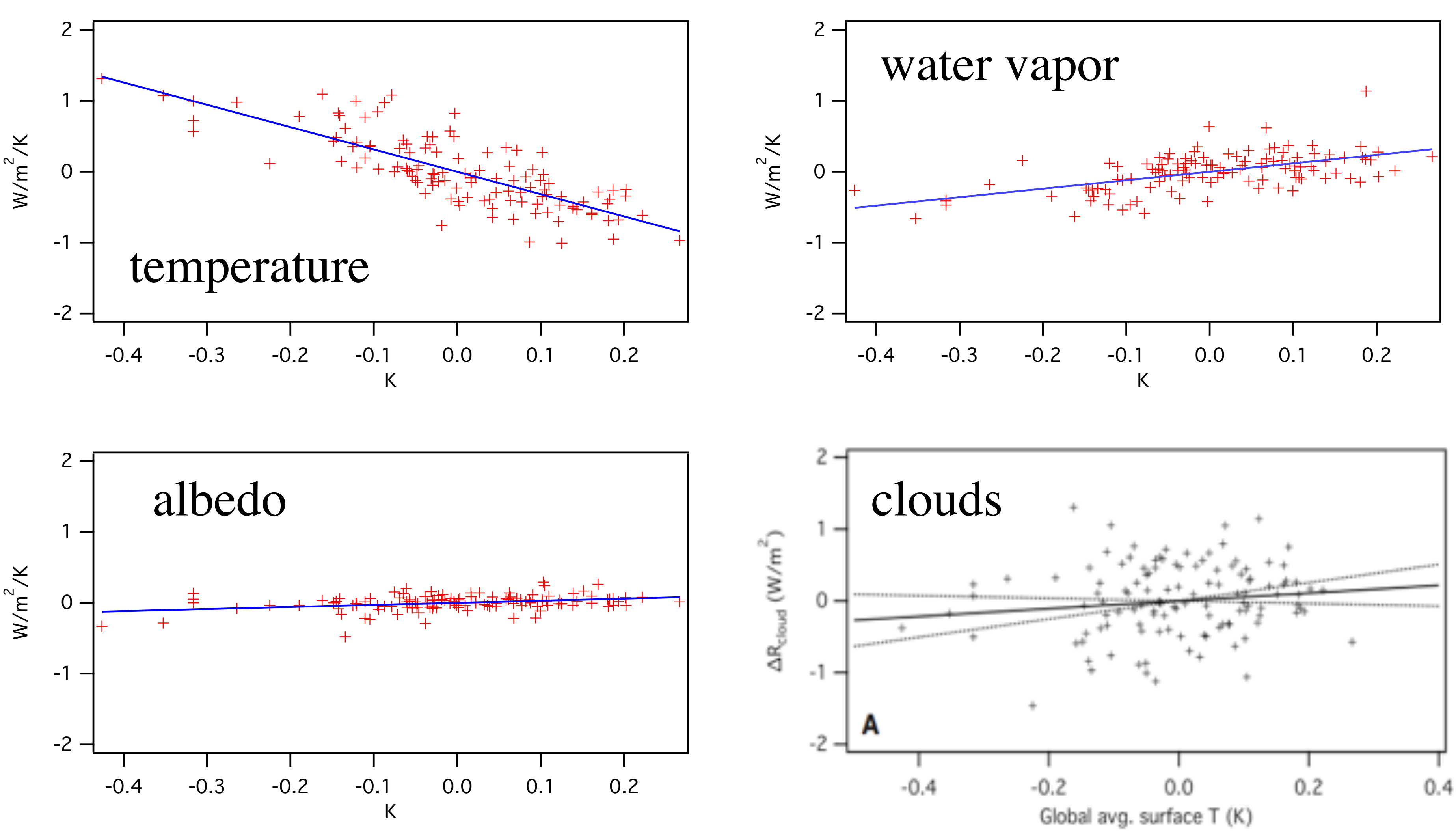
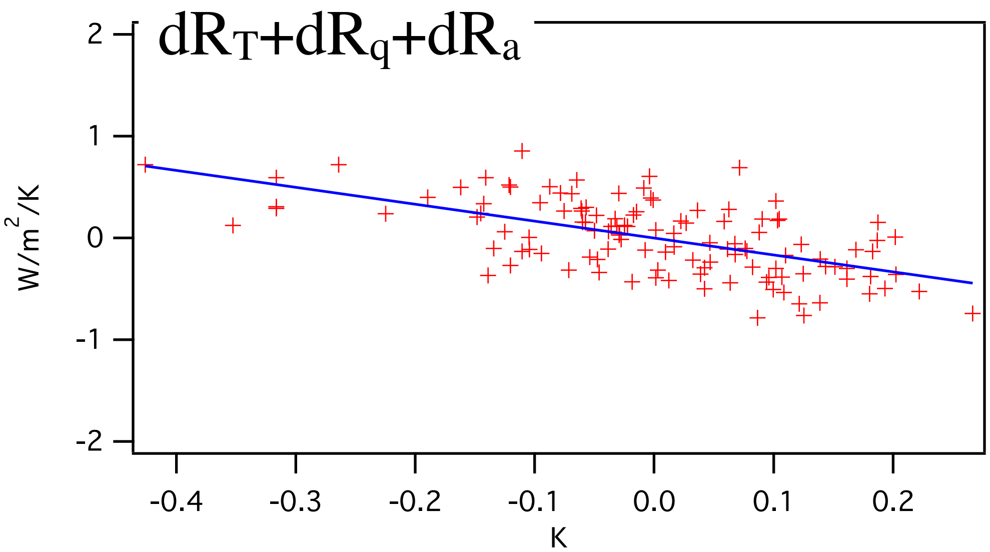


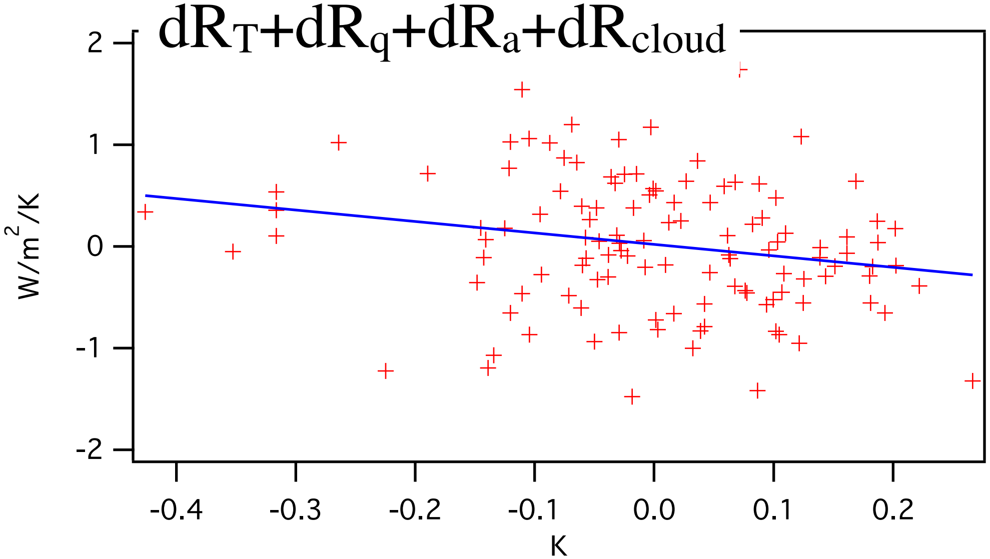
Fig. 2. (**A**) Scatter plot of monthly average values of ΔR_{cloud} versus ΔT_s using CERES and ECMWF interim data. (**B**) Scatter plot of monthly averages of the same quantities from 100 years of a control run of the ECHAM/MPI-OM model. In all plots, the solid line is a linear least-squares fit and the dotted lines are the 2σ confidence interval of the fit.

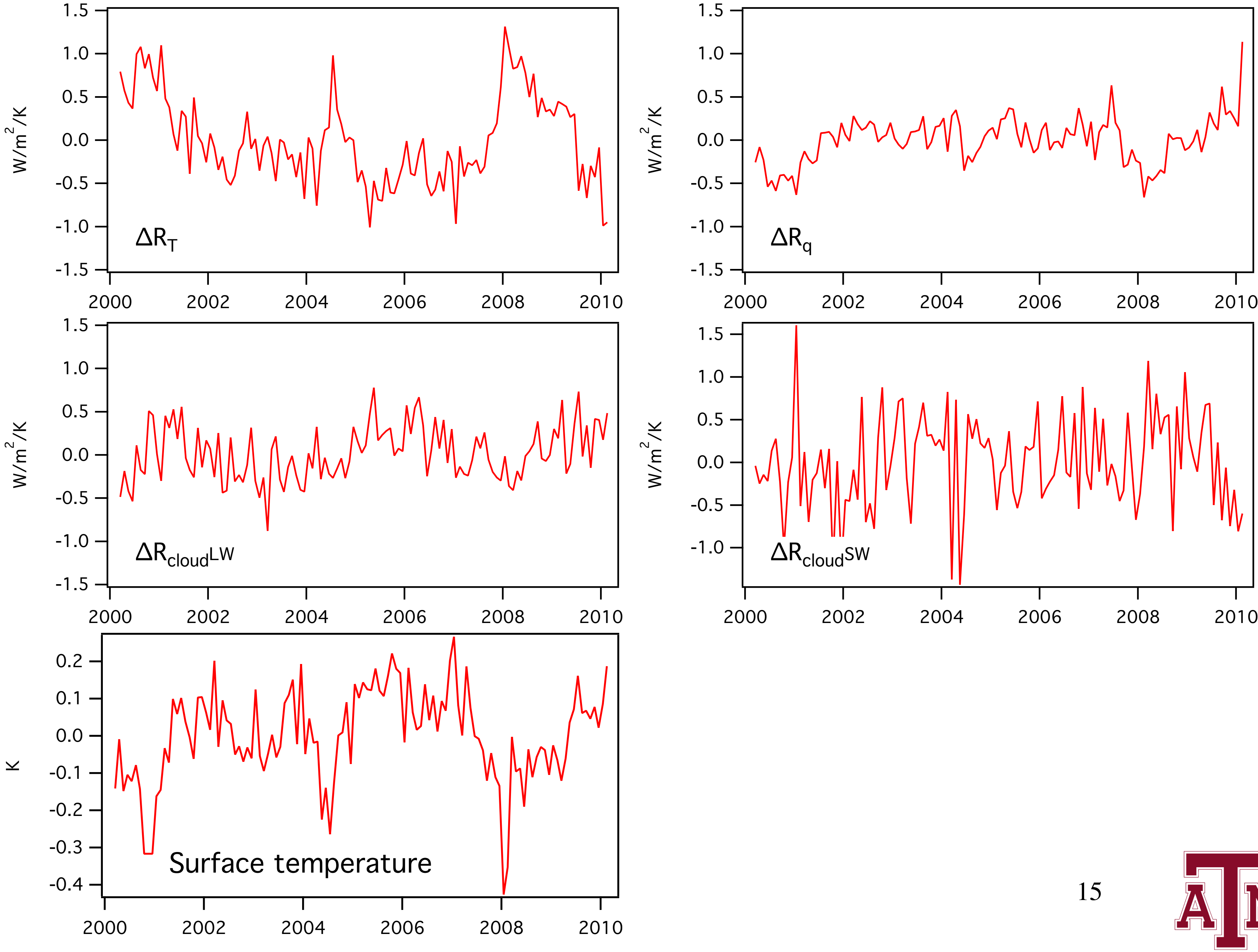


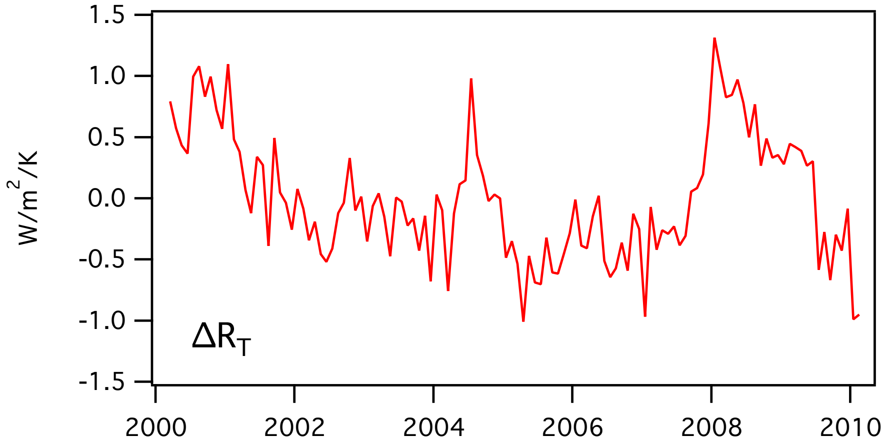
Dessler, 2010

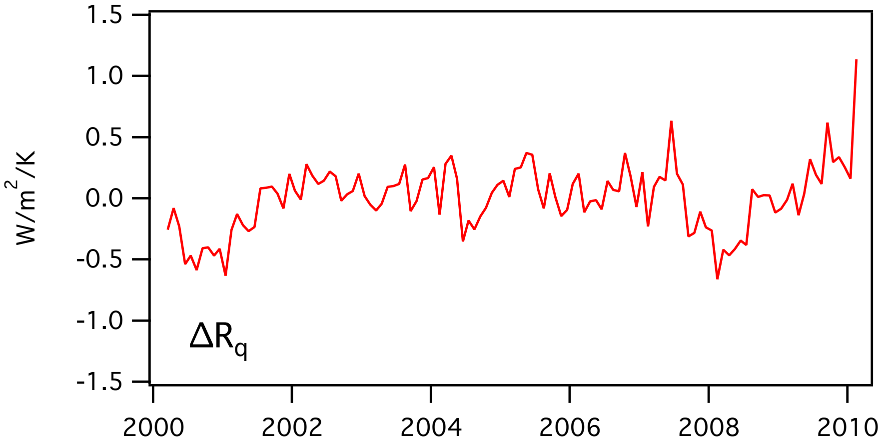

temperature
water vapor
albedo
clouds
W/m2/K
K
2
1
0
-1
-2
-0.4
-0.3
-0.2
-0.1
0.0
0.1
0.2
ΔRcloud (W/m2)
Global avg. surface T (K)
0.4
A

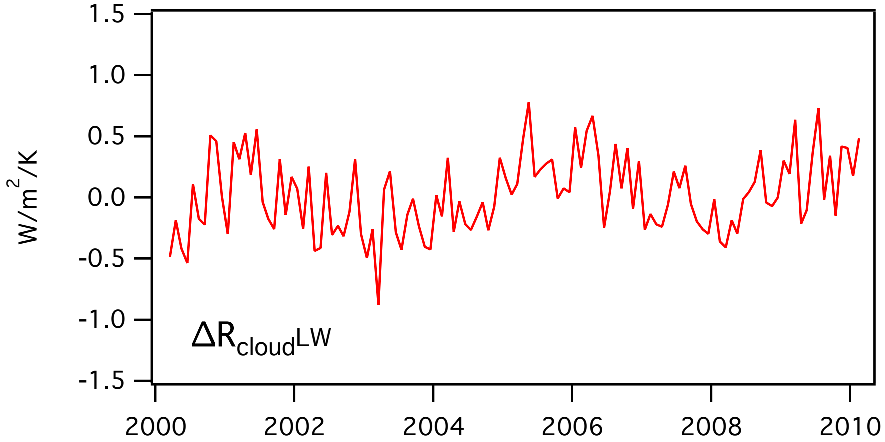

$dR_T+dR_q+dR_a$
W/m^2/K
K
2
1
0
-1
-2
-0.4
-0.3
-0.2
-0.1
0.0
0.1
0.2

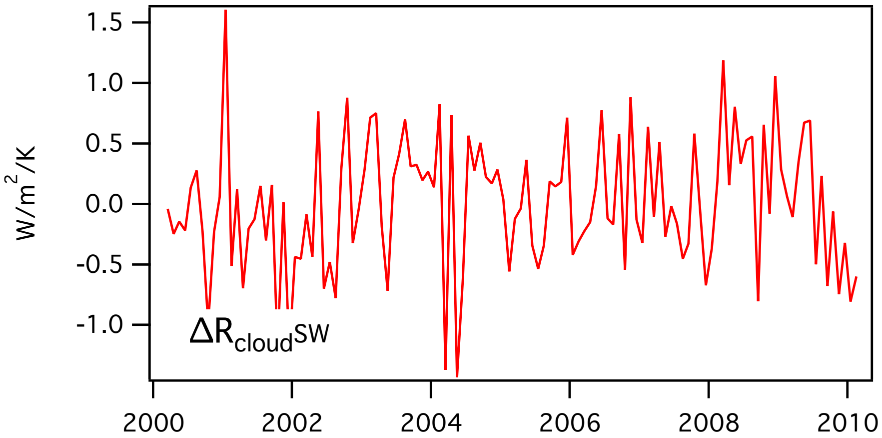

$dR_T+dR_q+dR_a+dR_{cloud}$
W/m^2/K
K
2
1
0
-1
-2
-0.4
-0.3
-0.2
-0.1
0.0
0.1
0.2

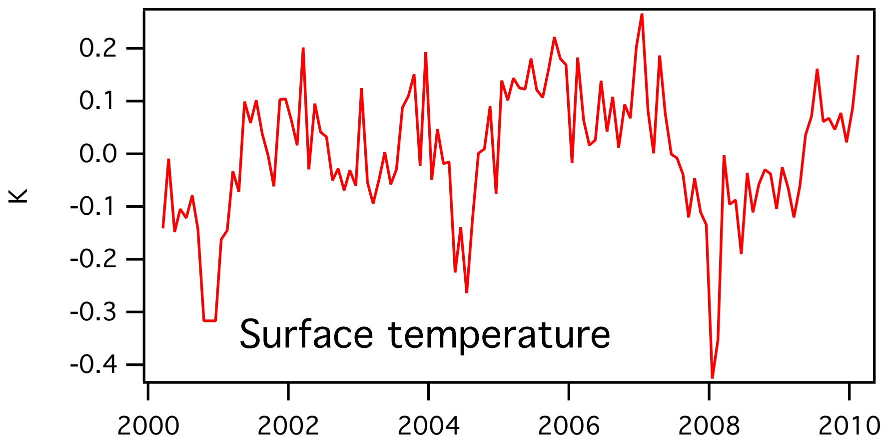

ΔR_T
ΔR_q
ΔR_cloudLW
ΔR_cloudSW
Surface temperature
W/m^2/K
K
2000
2002
2004
2006
2008
2010





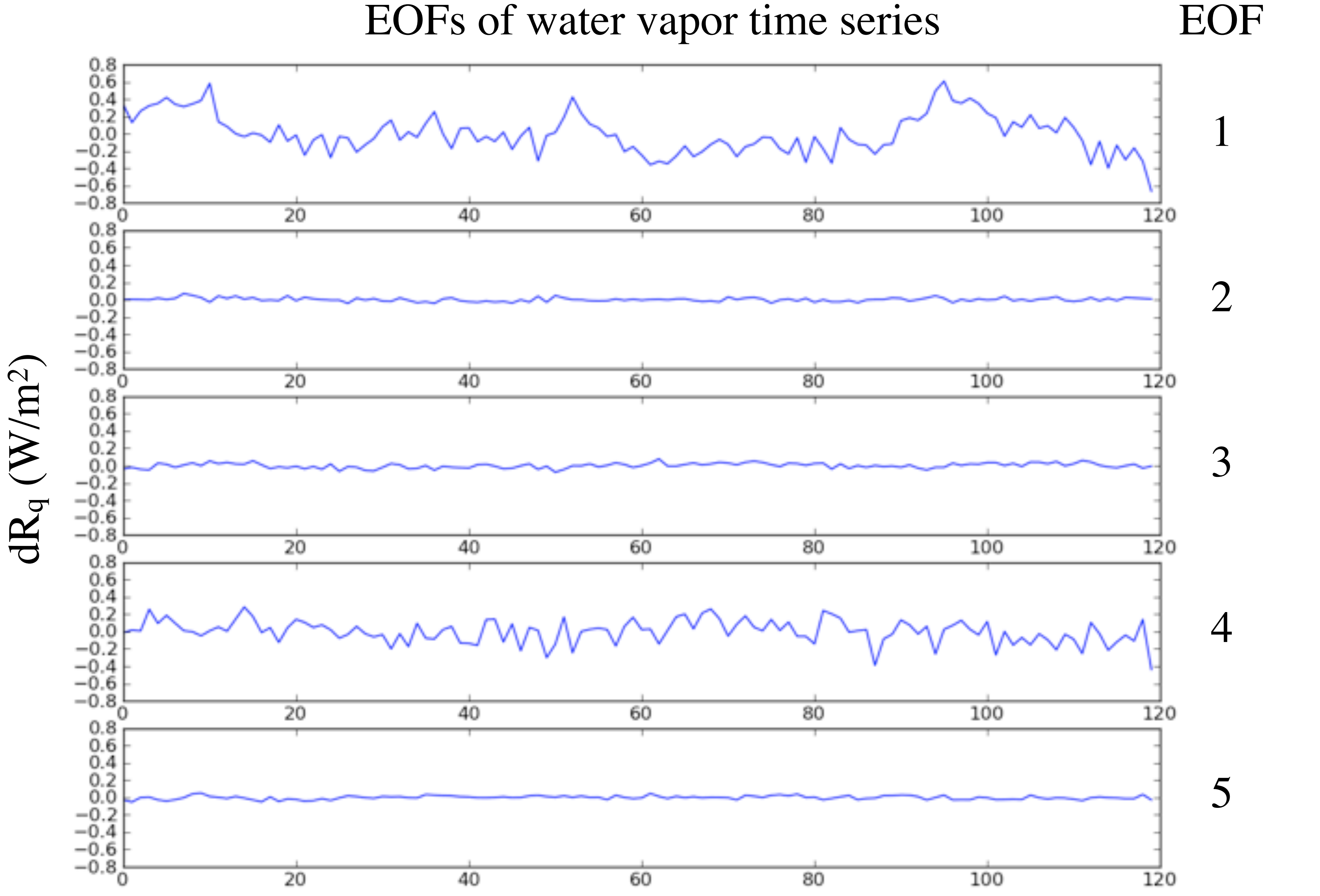


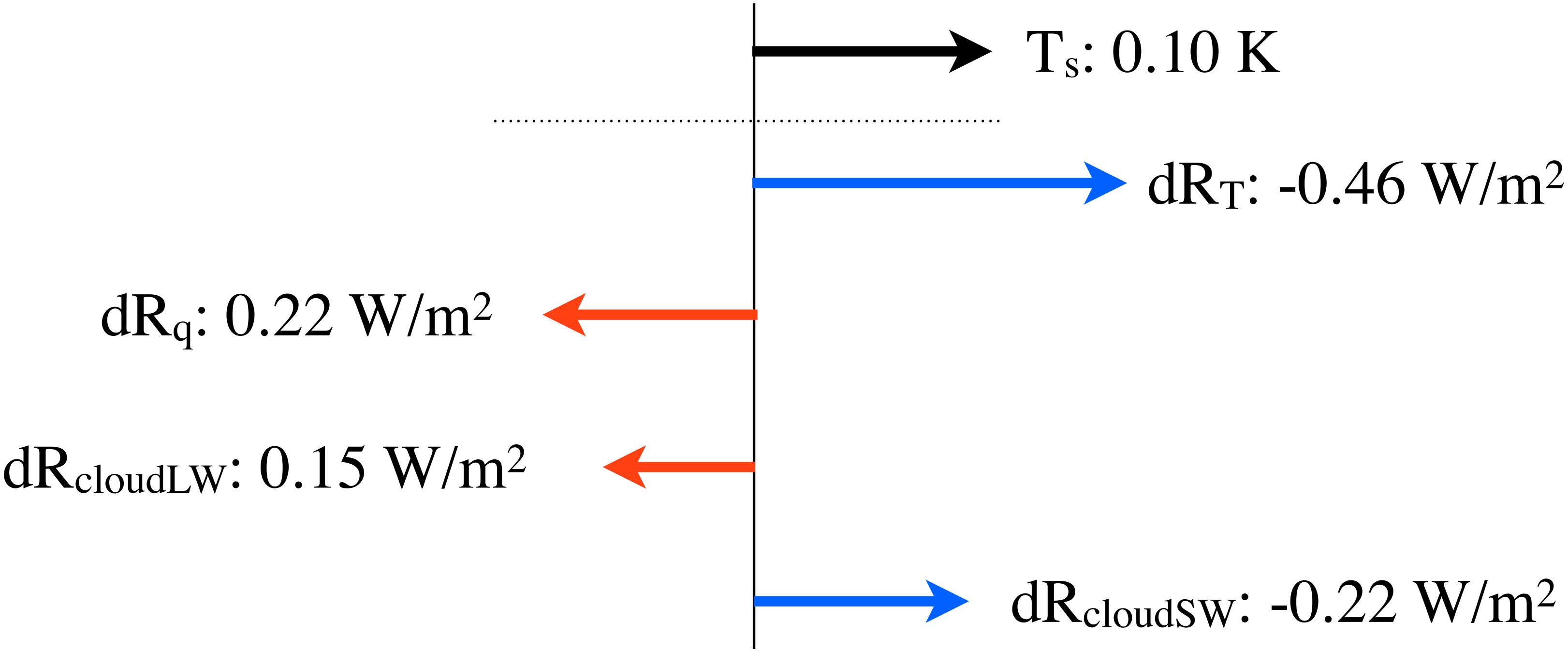




EOF analysis to find the modes of variability

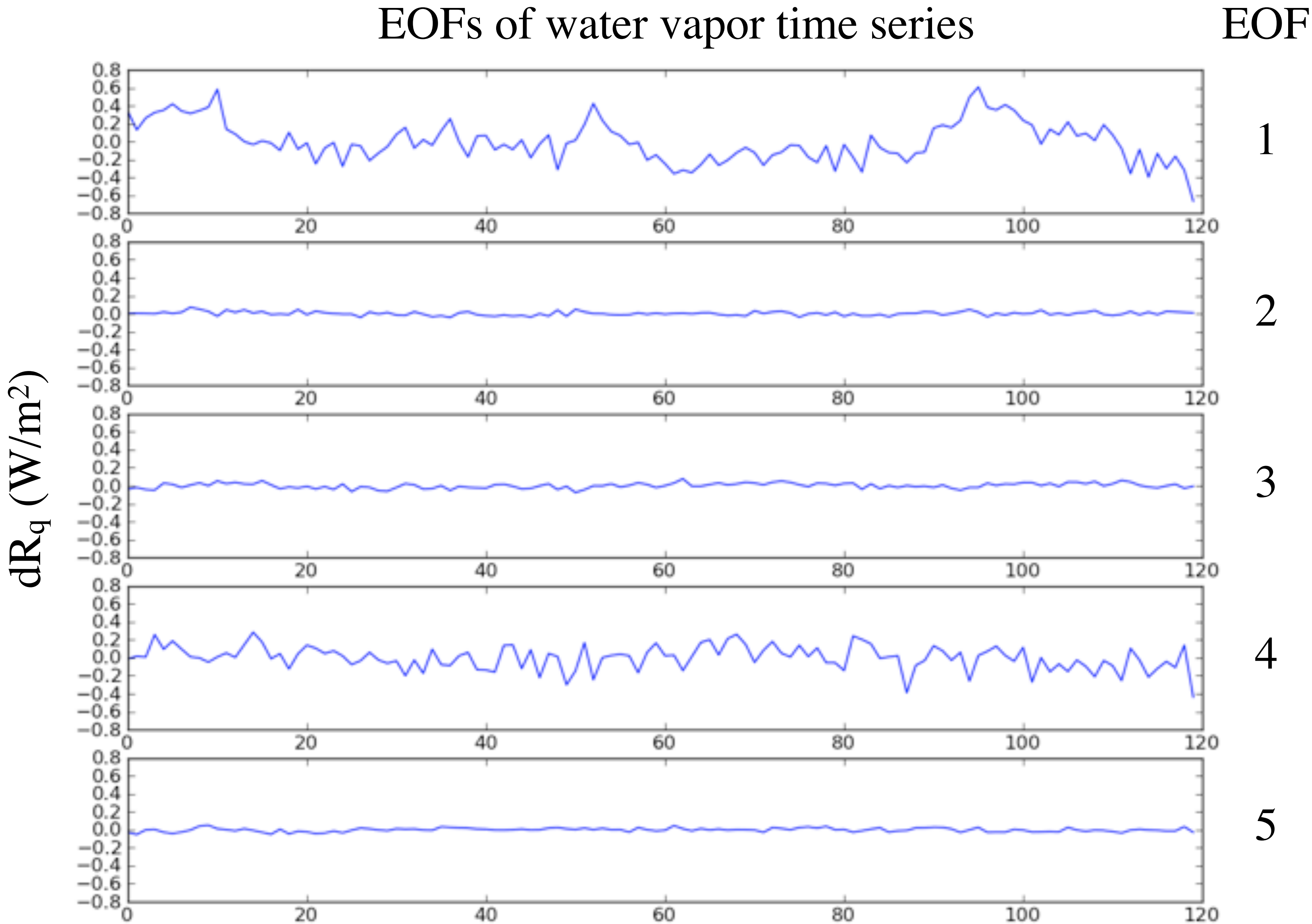
EOFs of water vapor time series

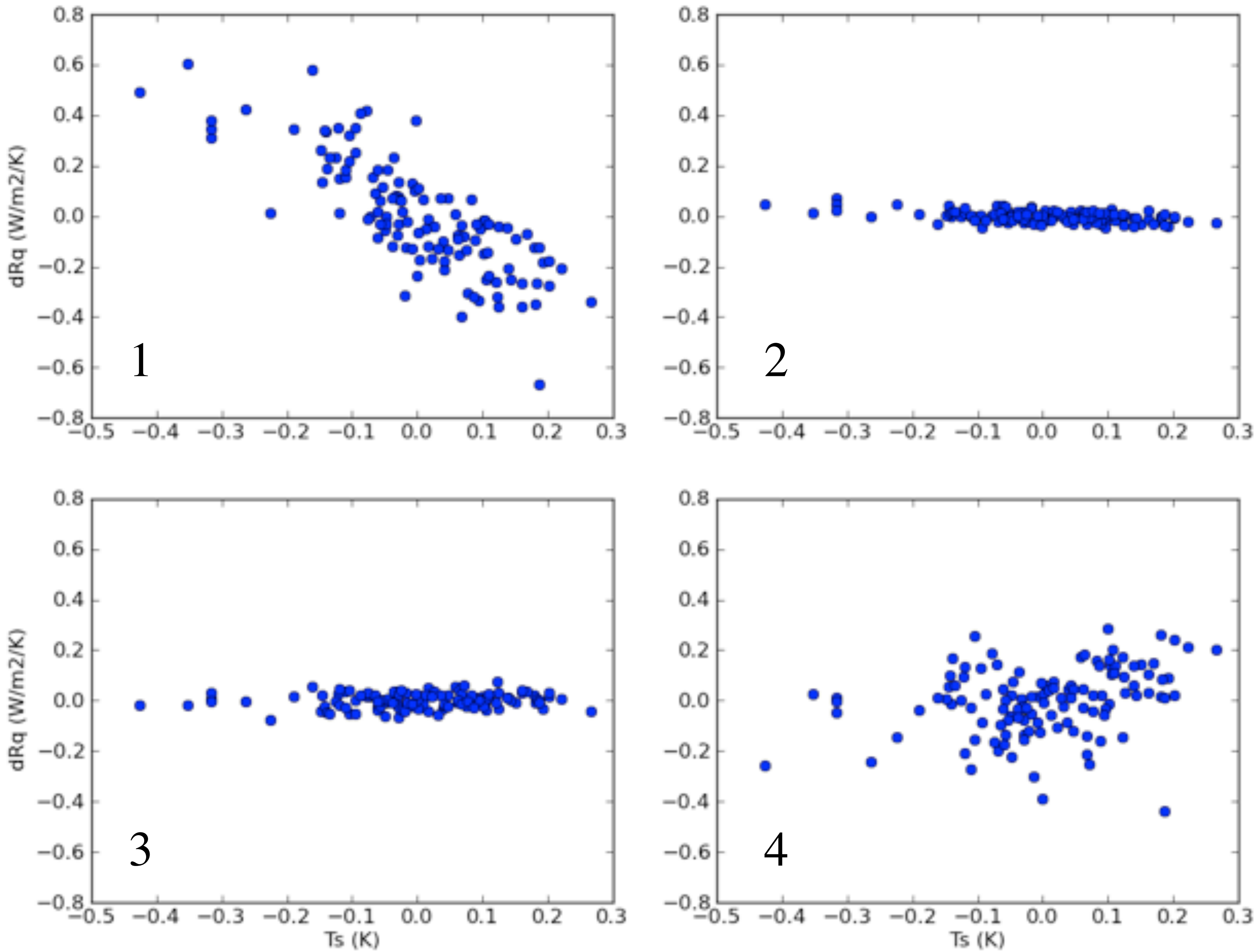




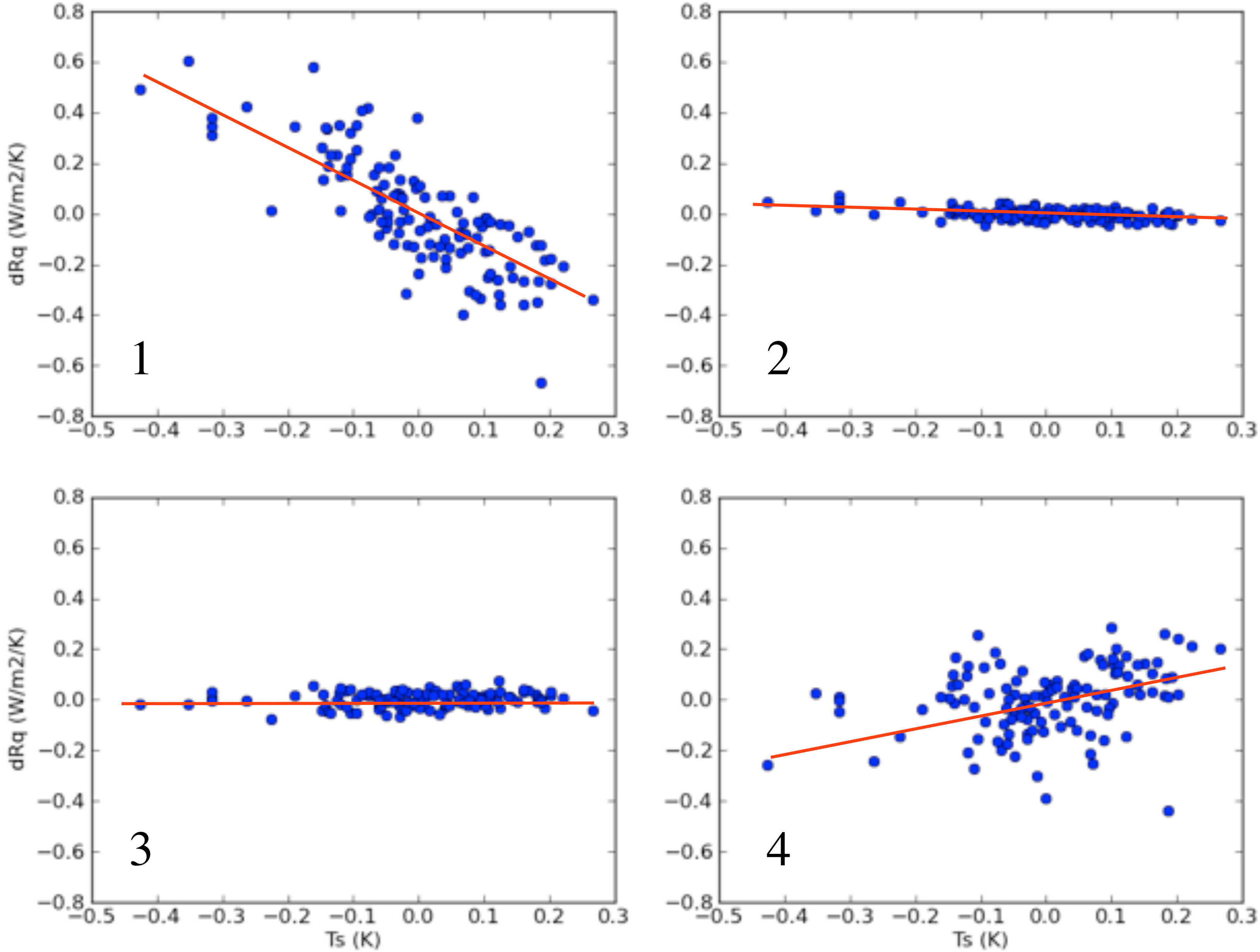
Explains 52% of variance

EOFs of water vapor time series





dRq (W/m2/K)
Ts (K)
1
2
3
4


dRq (W/m2/K)
Ts (K)
1
2
3
4
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−0.5
−0.4
−0.3
−0.2
−0.1
0.0
0.1
0.2
0.3

Feedback
W/m^2/K

52% 25% 12% 8% 3%

	EOF 1	EOF 2	EOF 3	EOF 4	EOF 5	total
dR_T	-2.91	-0.36	0.08	-0.17	0.24	-3.12
dR_q	1.42	0.08	-0.03	-0.32	0.04	1.18
$dR_{cloudLW}$	0.94	-0.71	0.22	-0.01	-0.02	0.42
$dR_{cloudSW}$	-1.36	1.47	0.29	-0.21	-0.08	0.11

tropical T

tropical +
extratrop T

extratropical T

Feedback
W/m^2/K

	EOF 1	EOF 2	EOF 3	EOF 4	EOF 5	total
dR_T	-2.91	-0.36	0.08	-0.17	0.24	-3.12
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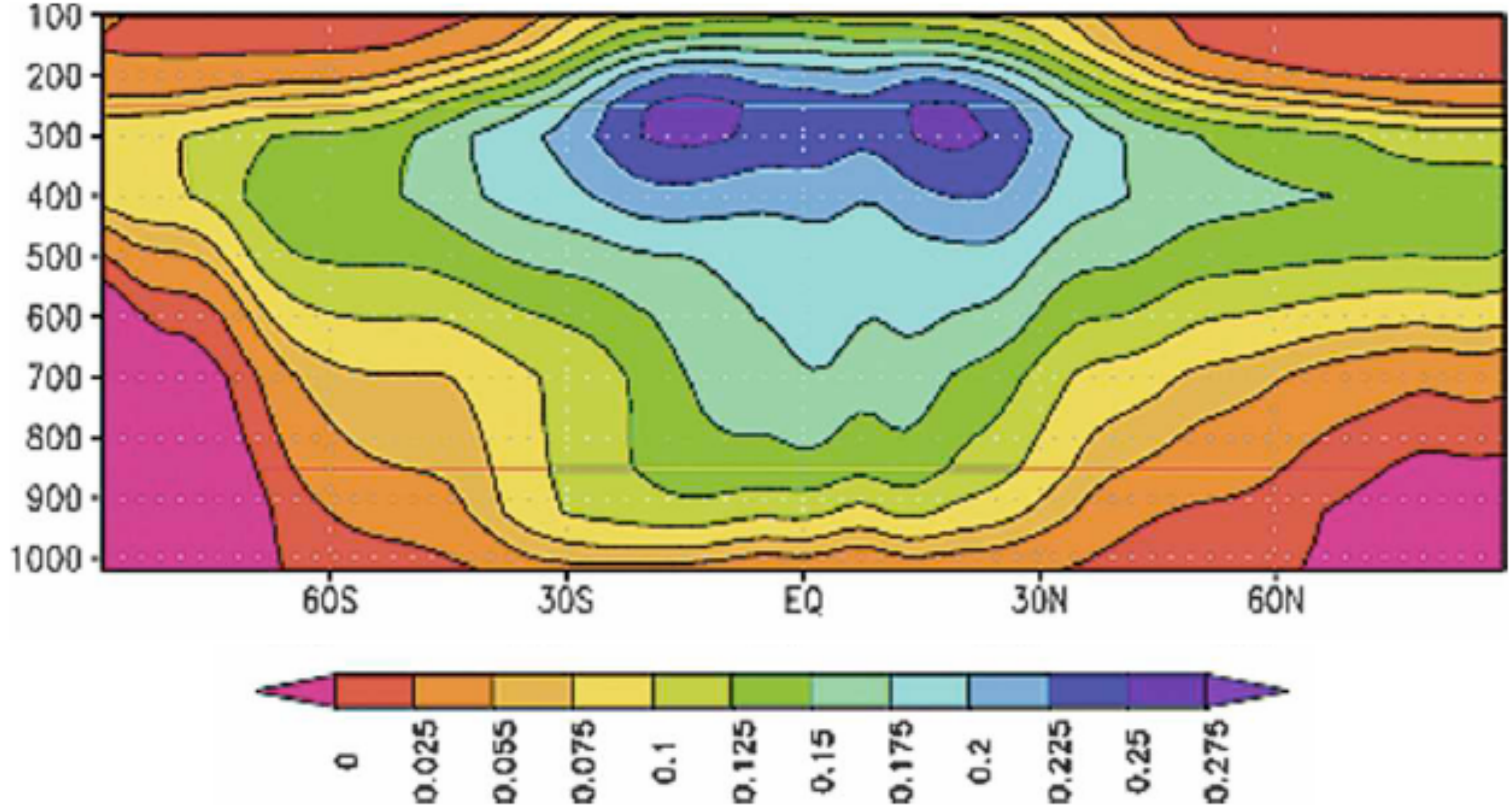
tropical T

extratropical T

tropical +
extratrop T

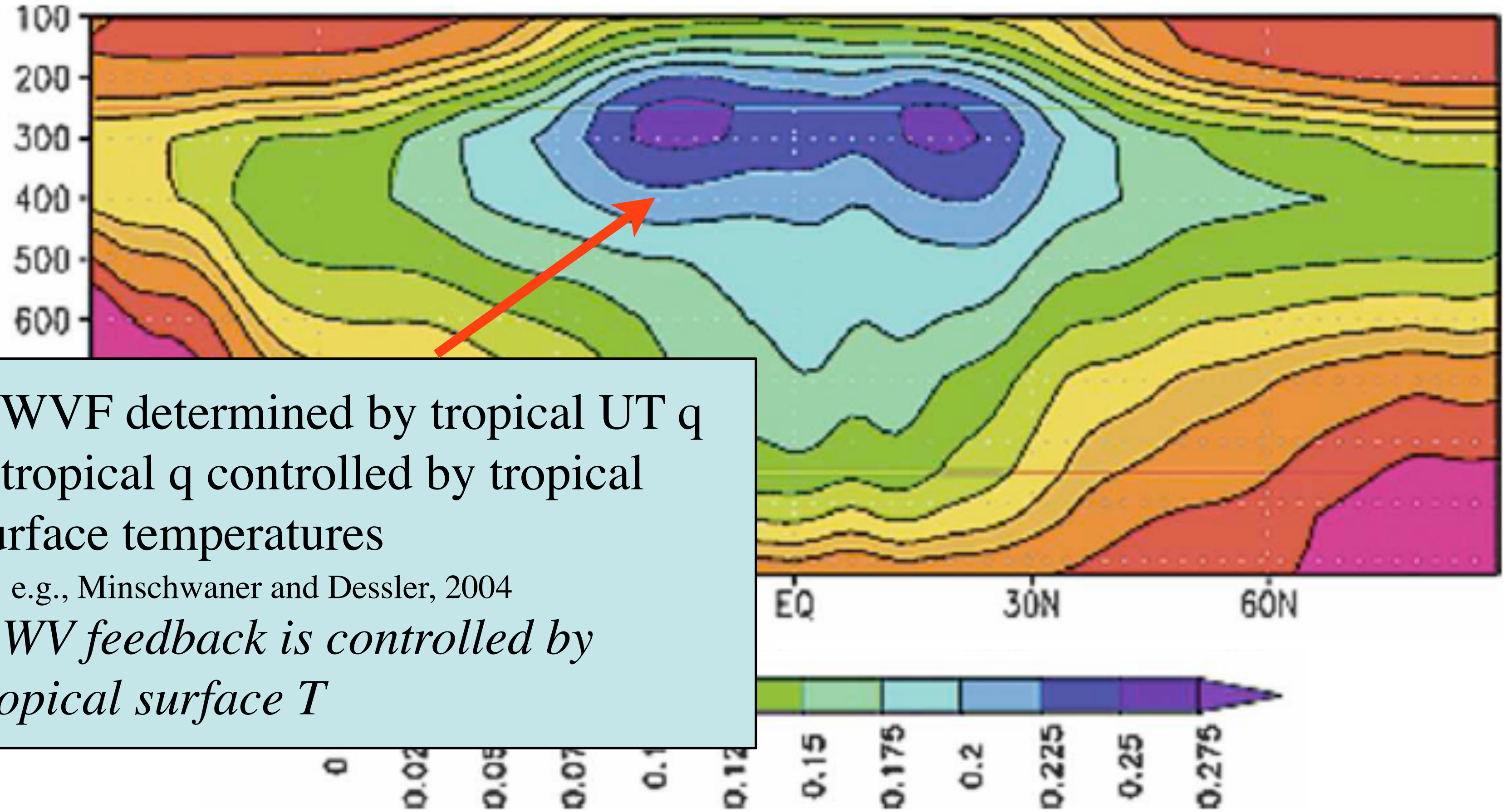
Water vapor feedback is primarily a “tropical” phenomenon



Change in R per unit change in q(x,y,z): ΔR/Δq(x,y,z)

Fig. 2 of Soden et al., 2008

Water vapor feedback is primarily a "tropical" phenomenon



* WVF determined by tropical UT q

* tropical q controlled by tropical surface temperatures

e.g., Minschwaner and Dessler, 2004

* *WV feedback is controlled by tropical surface T*

Change in R per unit change in q(x,y,z): $\Delta R/\Delta q(x,y,z)$

Fig. 2 of Soden et al., 2008

Feedback
W/m^2/K

	EOF 1	EOF 2	EOF 3	EOF 4	EOF 5	total
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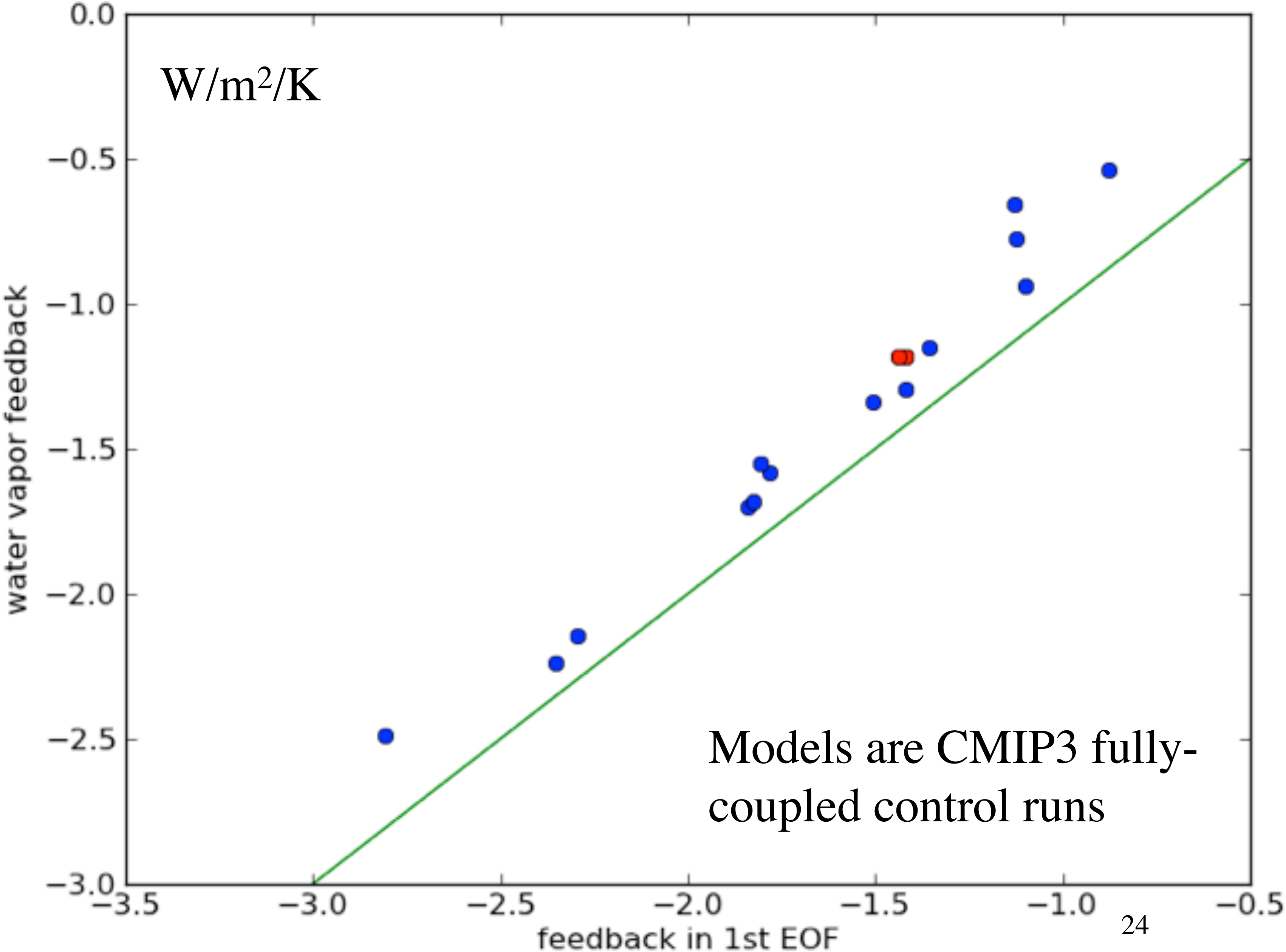
tropical T

extratropical T

tropical +
extratrop T


W/m2/K
water vapor feedback
feedback in 1st EOF
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
−3.5
−3.0
−2.5
−2.0
−1.5
−1.0
−0.5
Models are CMIP3 fully-coupled control runs

Feedback
W/m²/K

	EOF 1	EOF 2	EOF 3	EOF 4	EOF 5	total
dR_T	-2.91	-0.36	0.08	-0.17	0.24	-3.12
dR_q	1.42	0.08	-0.03	-0.32	0.04	1.18
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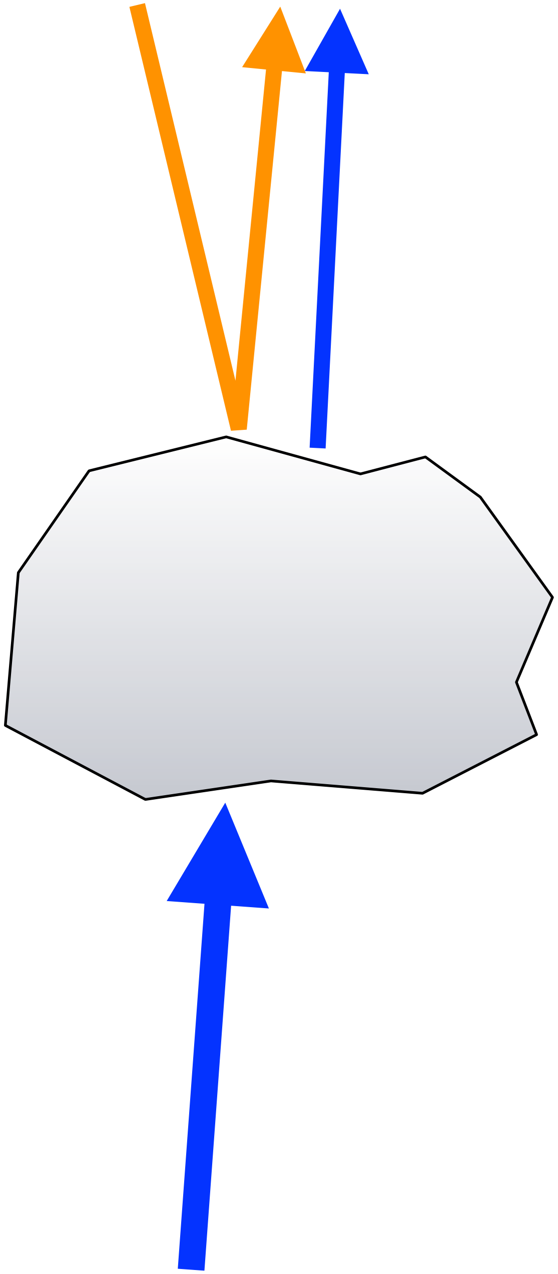
tropical T

extratropical T

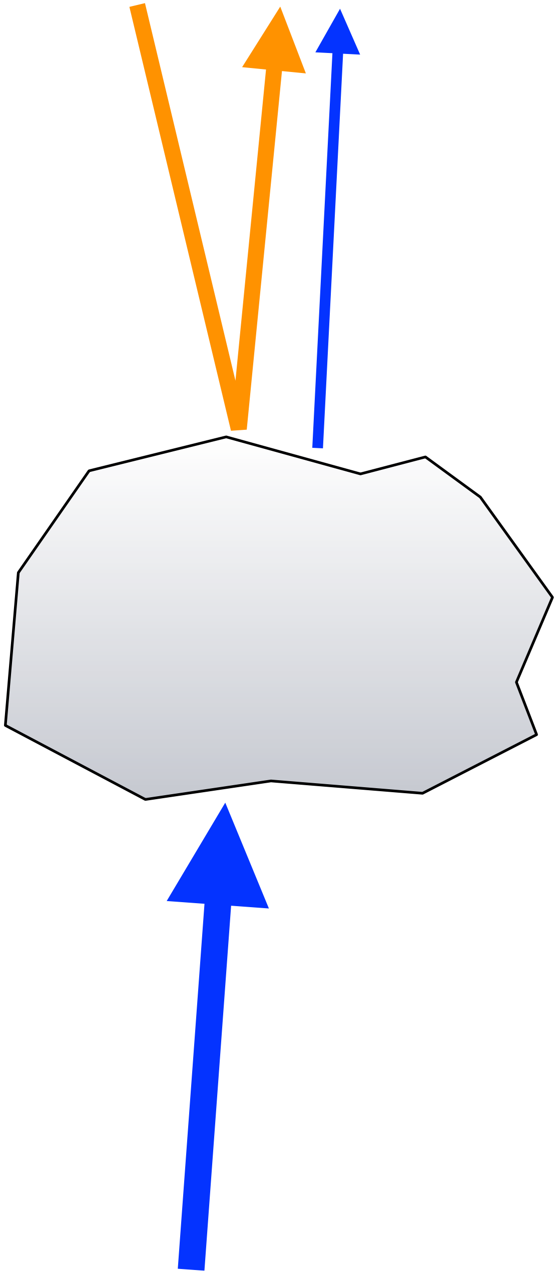
tropical +
extratrop T



Effect of clouds on top-of-atmosphere (TOA) flux

1) reduce incoming solar: cool
2) reduce outgoing IR: warm

net effect is the difference between these effects

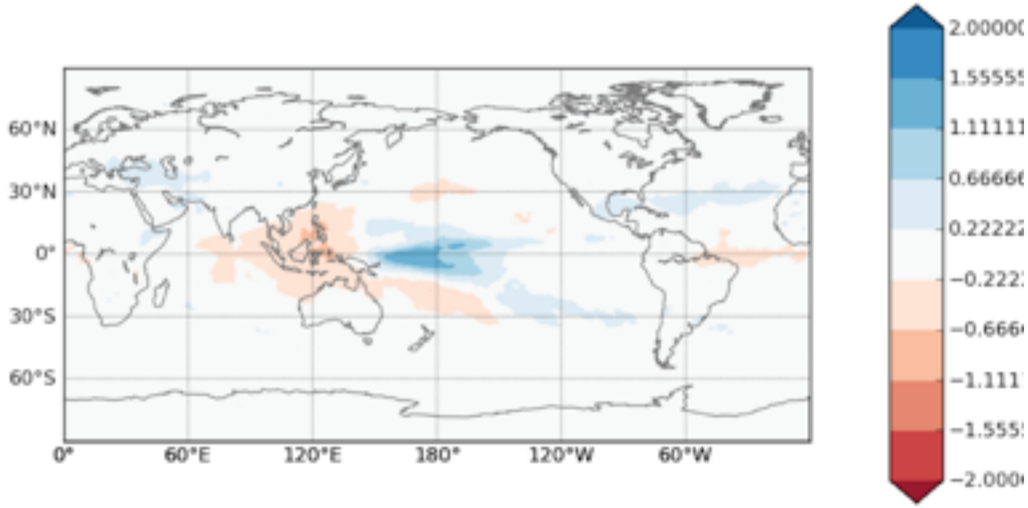


in today's atmosphere, clouds reduce net energy in to the Earth by 20 W/m^2 (also known as cloud radiative forcing)

how will this change in a future climate?

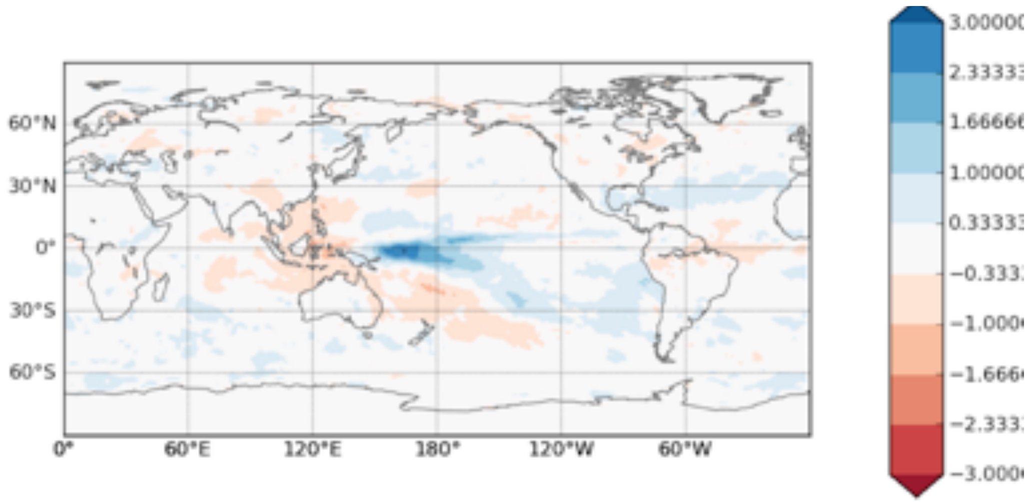
if changing clouds further reduce TOA downward net flux, this is a negative feedback

if changing clouds increase TOA downward net flux, this is a positive feedback



LW EOF 1

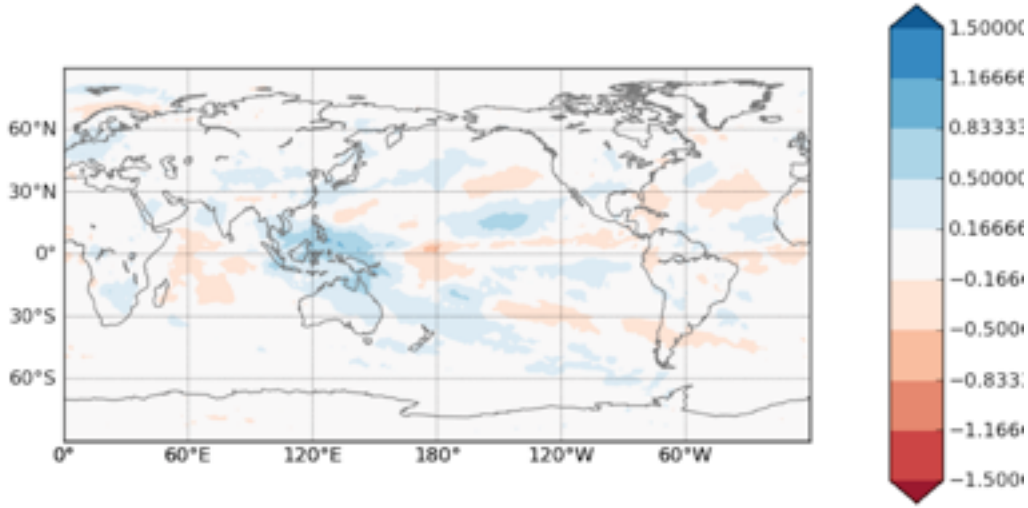
Covariance of PC1 vs. time series at each grid point of LW and SW energy trapped by clouds



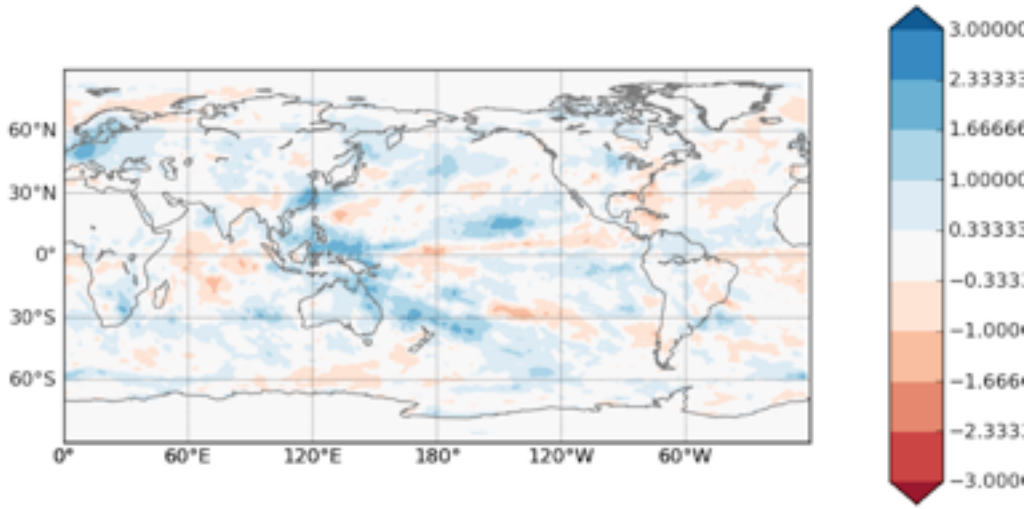
SW EOF 1

Conclusions

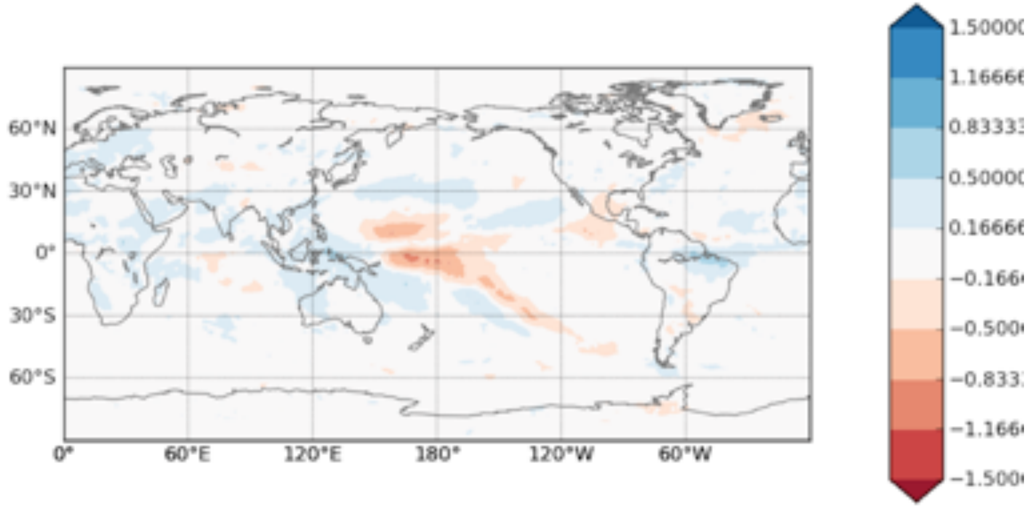
- Clouds that make it difficult to accurately determine how TOA flux anomaly varies with surface temperature
  - they correlate poorly with surface T
  - next steps: use EOF analysis to gain insight into the factors that regulate clouds
  - goal is to improve estimate of clouds vs. T
- Water vapor and temperature are well behaved



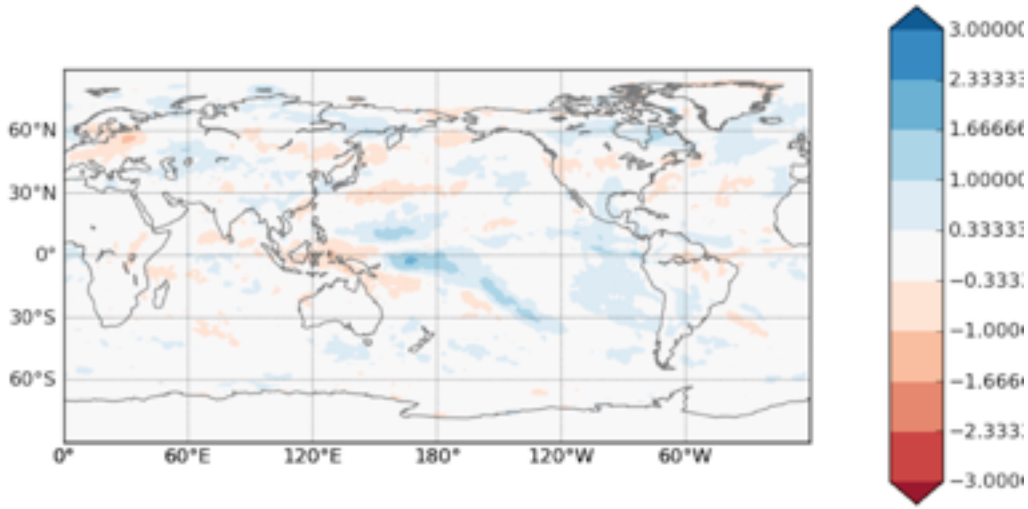
LW EOF 2



SW EOF 2



LW EOF 3



SW EOF 3

Feedback
W/m^2/K

	EOF 1	EOF 2	EOF 3	EOF 4	EOF 5	total
dR_T	-2.91	-0.36	0.08	-0.17	0.24	-3.12
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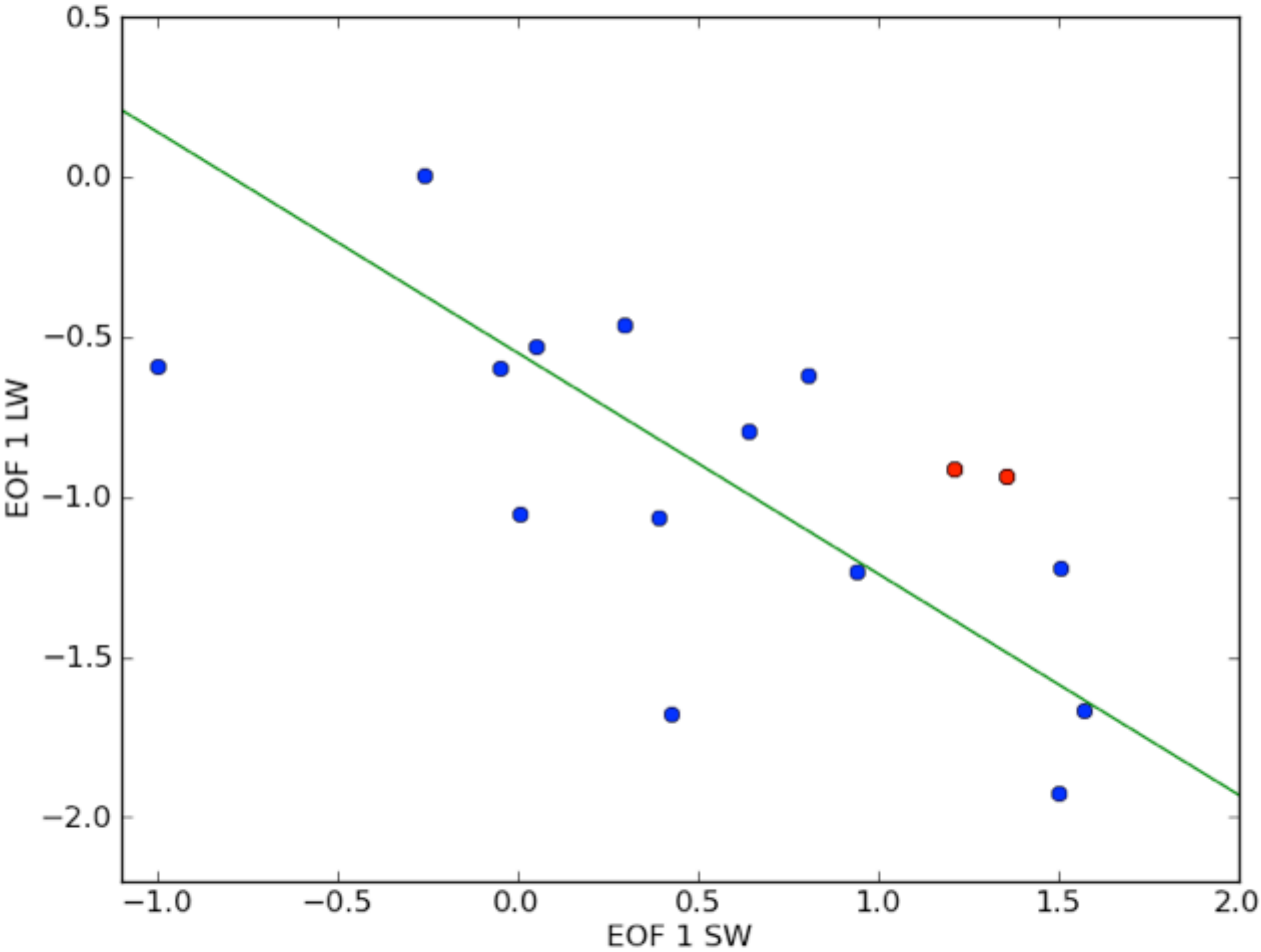
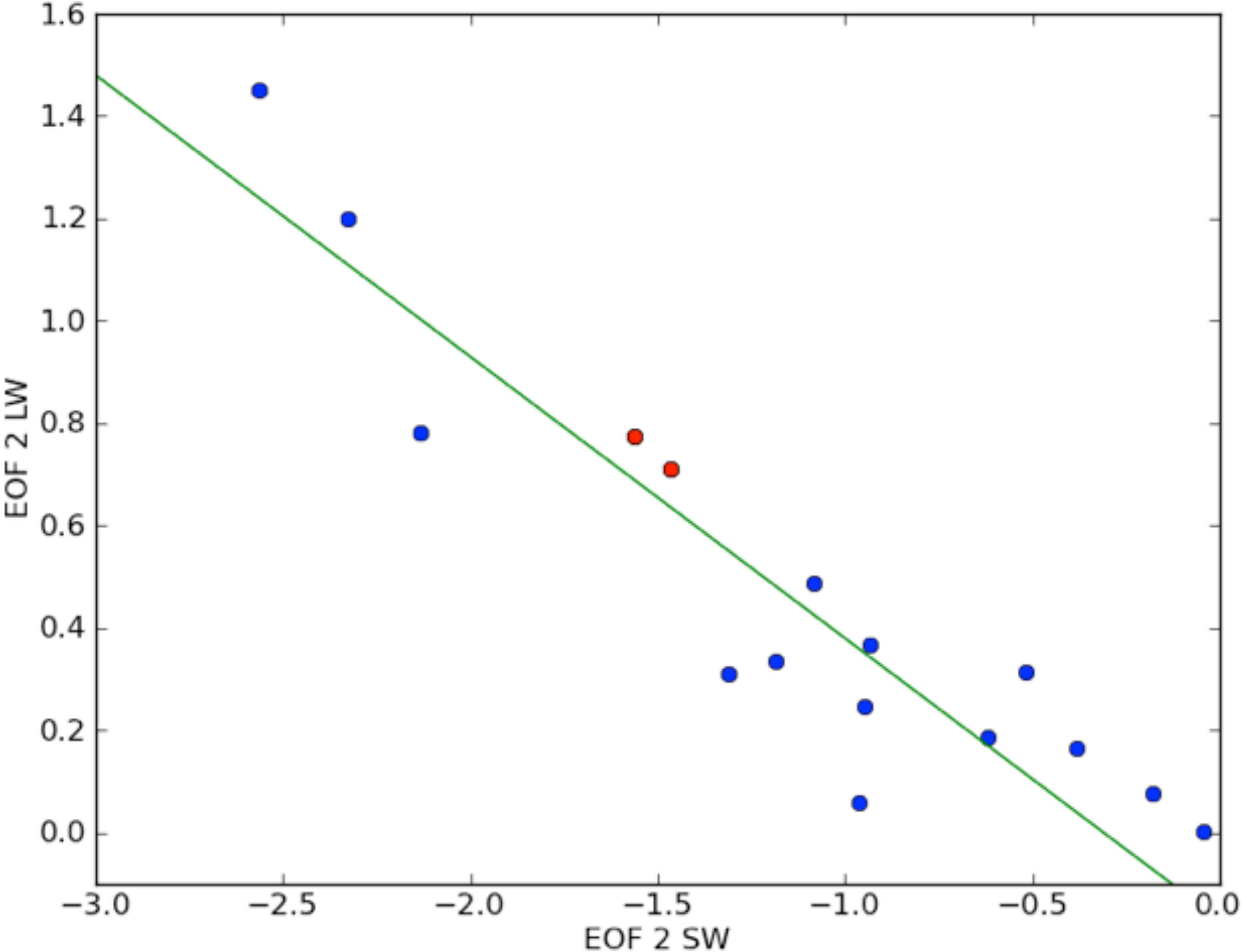
tropical T

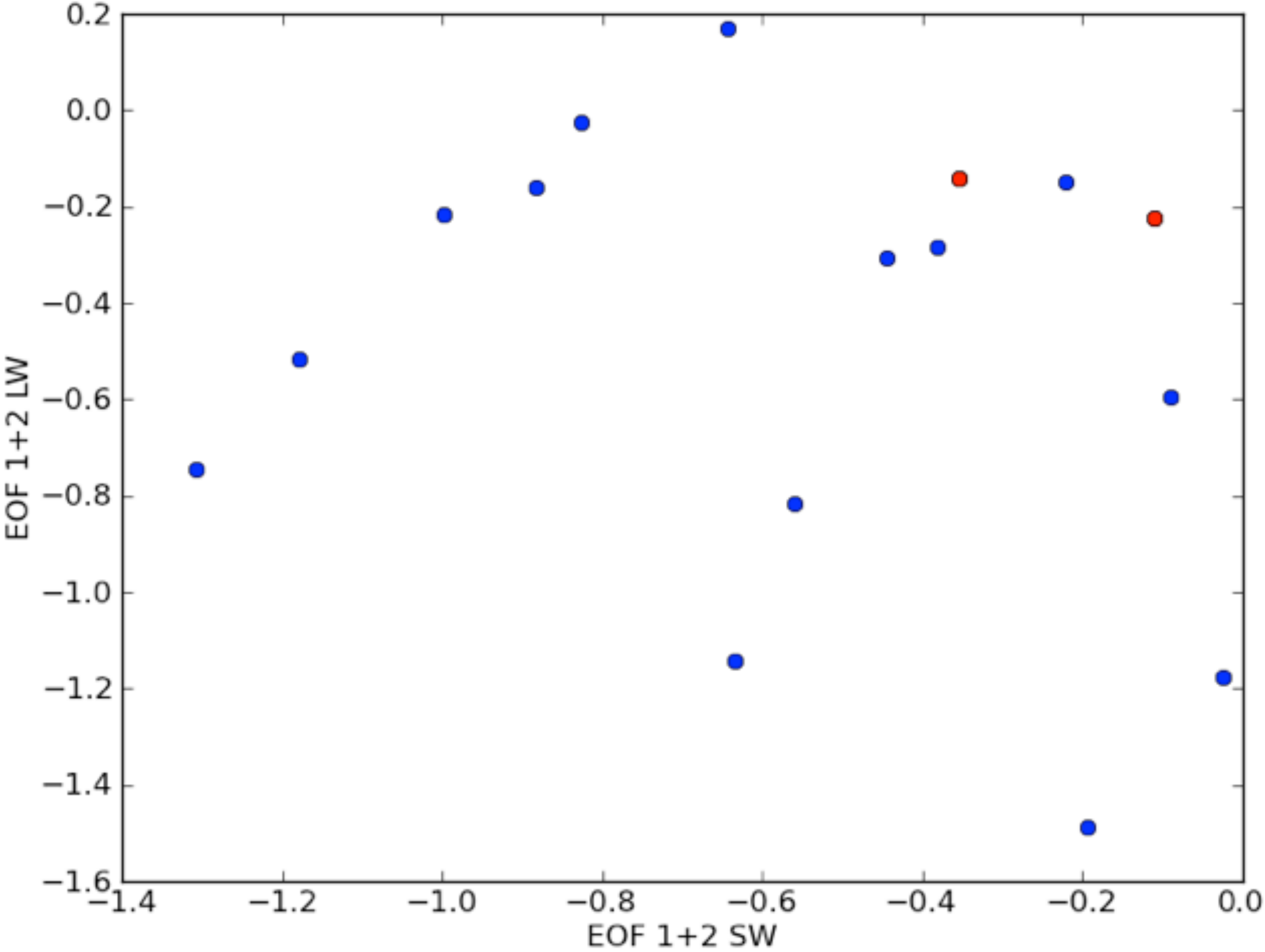
extratropical T

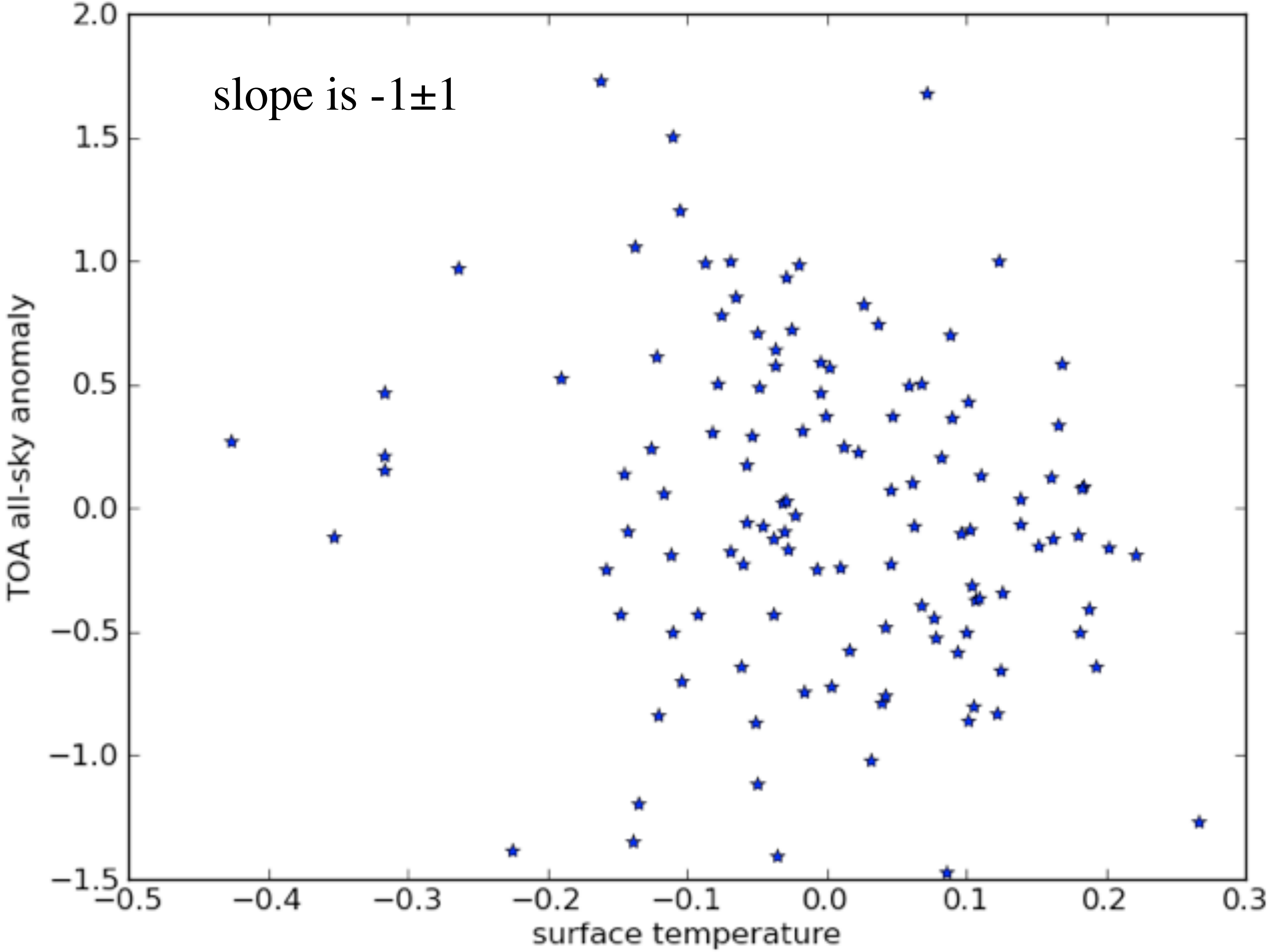
tropical +
extratrop T



0.5
0.0
−0.5
−1.0
−1.5
−2.0
EOF 1 LW
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
EOF 1 SW


1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
EOF 2 LW
−3.0
−2.5
−2.0
−1.5
−1.0
−0.5
0.0
EOF 2 SW


0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
−1.4
−1.6
−1.4
−1.2
−1.0
−0.8
−0.6
−0.4
−0.2
0.0
EOF 1+2 LW
EOF 1+2 SW


slope is -1±1
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
TOA all-sky anomaly
−0.5
−0.4
−0.3
−0.2
−0.1
0.0
0.1
0.2
0.3
surface temperature

to determine ΔR_{cloud}

- start with cloud radiative forcing (ΔCRF); change in TOA flux if clouds are removed
- $\Delta CRF = (\Delta R_{clear\text{-}sky} - \Delta R_{all\text{-}sky})$
- ΔCRF can also be affected by changes in T, q, albedo, radiative forcing
- Soden et al. [2008] adjustment to get ΔR_{cloud} from ΔCRF; see also Shell et al. [2008]

$$\Delta R_{cloud} = \Delta CRF + ({K^0}_T - K_T)dT + ({K^0}_W - K_W)dW$$

$$+ ({K^0}_a - K_a)da + (G^0 - G).$$

$$\Delta R_{cloud} = \left(\Delta R_{clear-sky} - \Delta R_{all-sky}\right) + (K^0{}_T - K_T)dT + (K^0{}_W - K_W)dW$$
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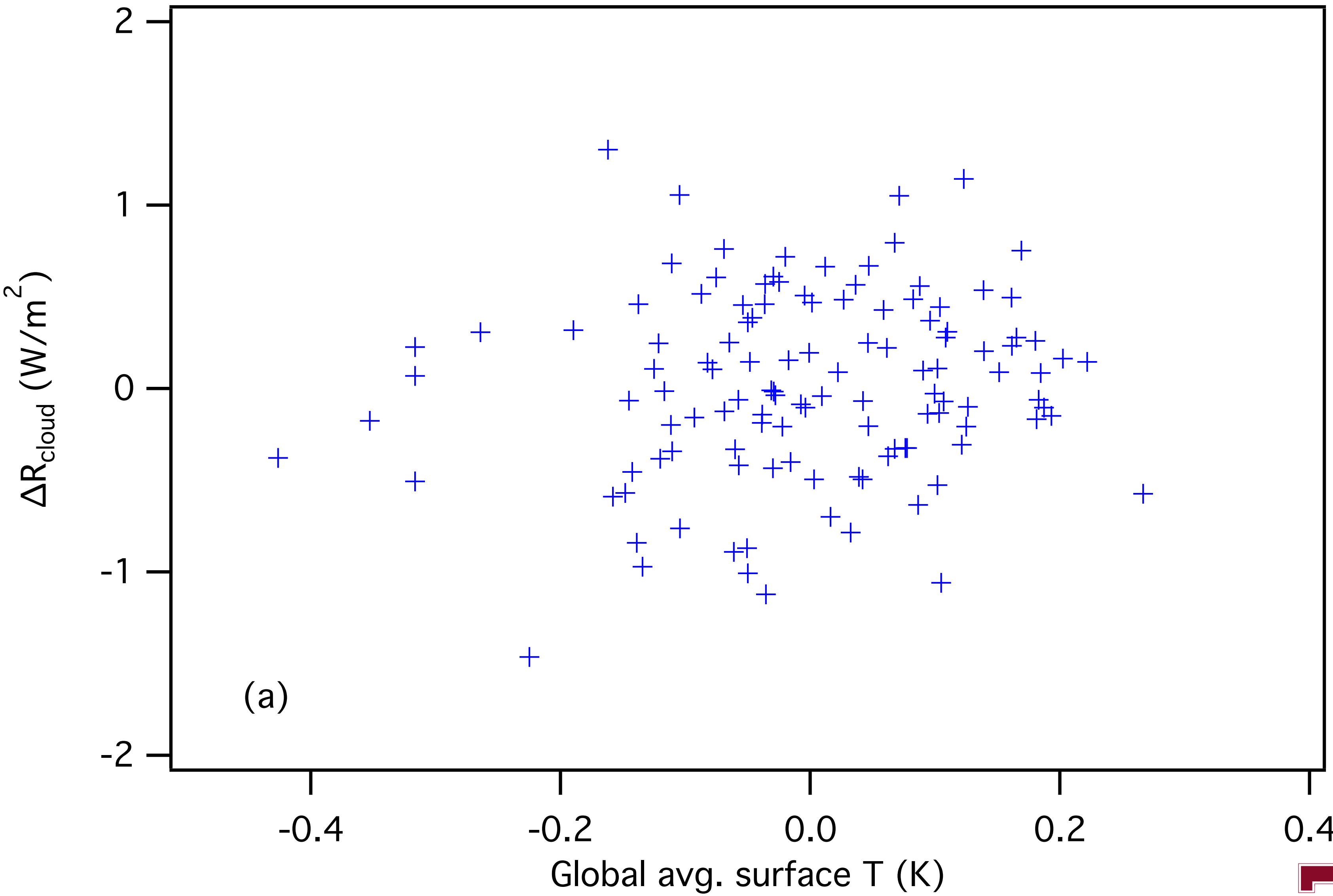
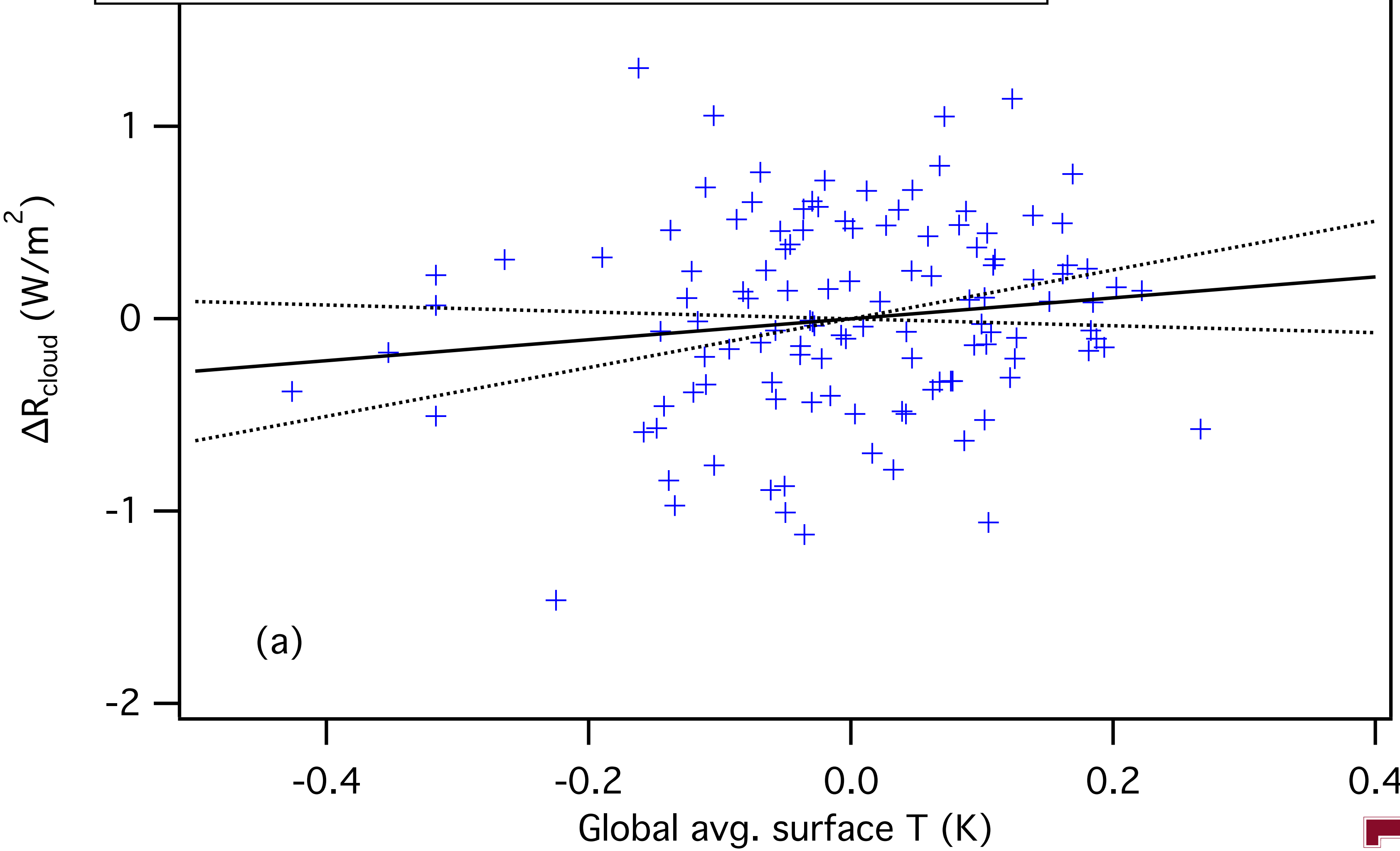
adjustment terms



2
1
0
-1
-2
(a)
-0.4
-0.2
0.0
0.2
0.4
Global avg. surface T (K)
ΔR_cloud (W/m²)

λ_{cloud} = 0.54±0.72 (2σ) W/m²/K (ECMWF)
= 0.46±0.75 (2σ) W/m²/K (MERRA)



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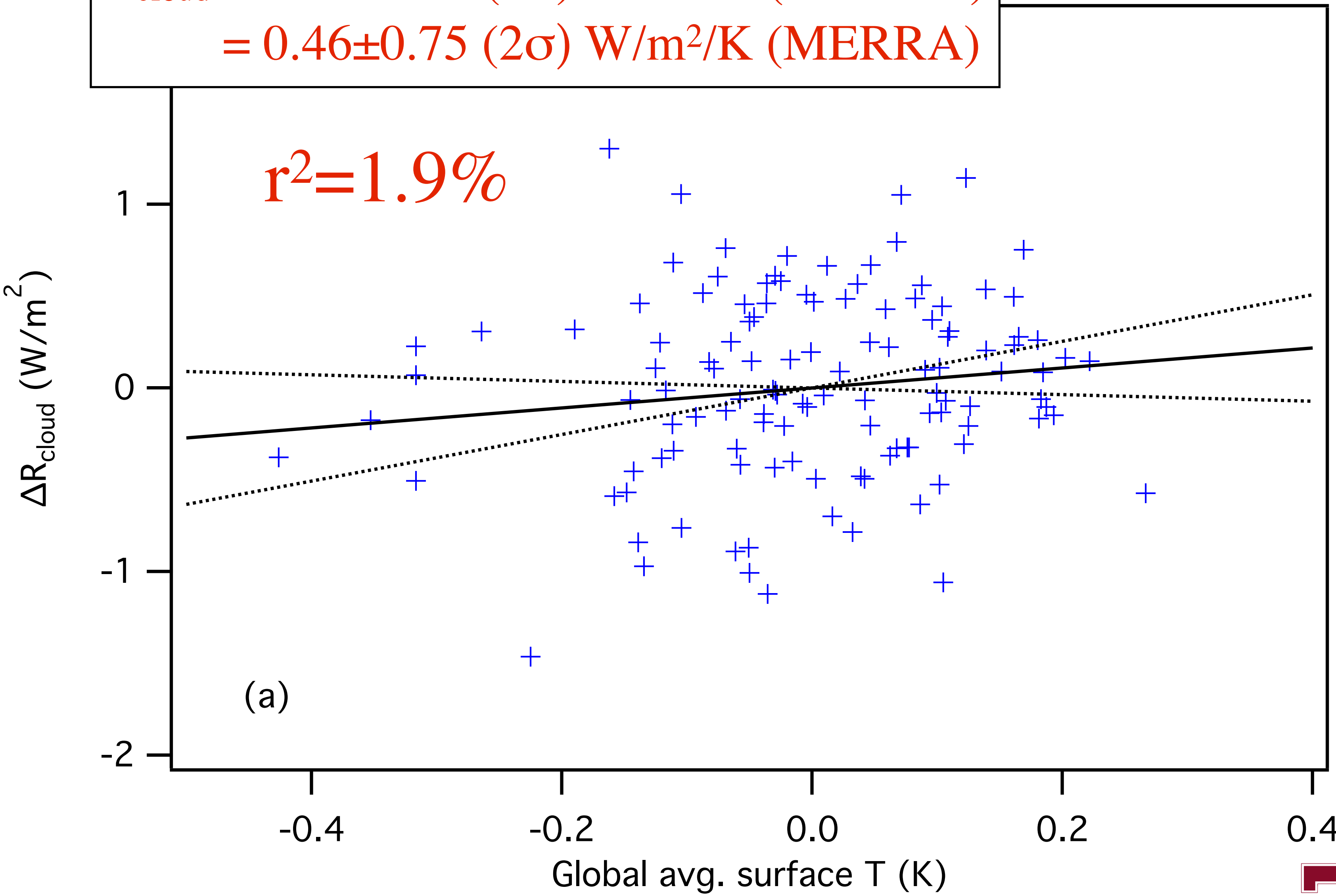
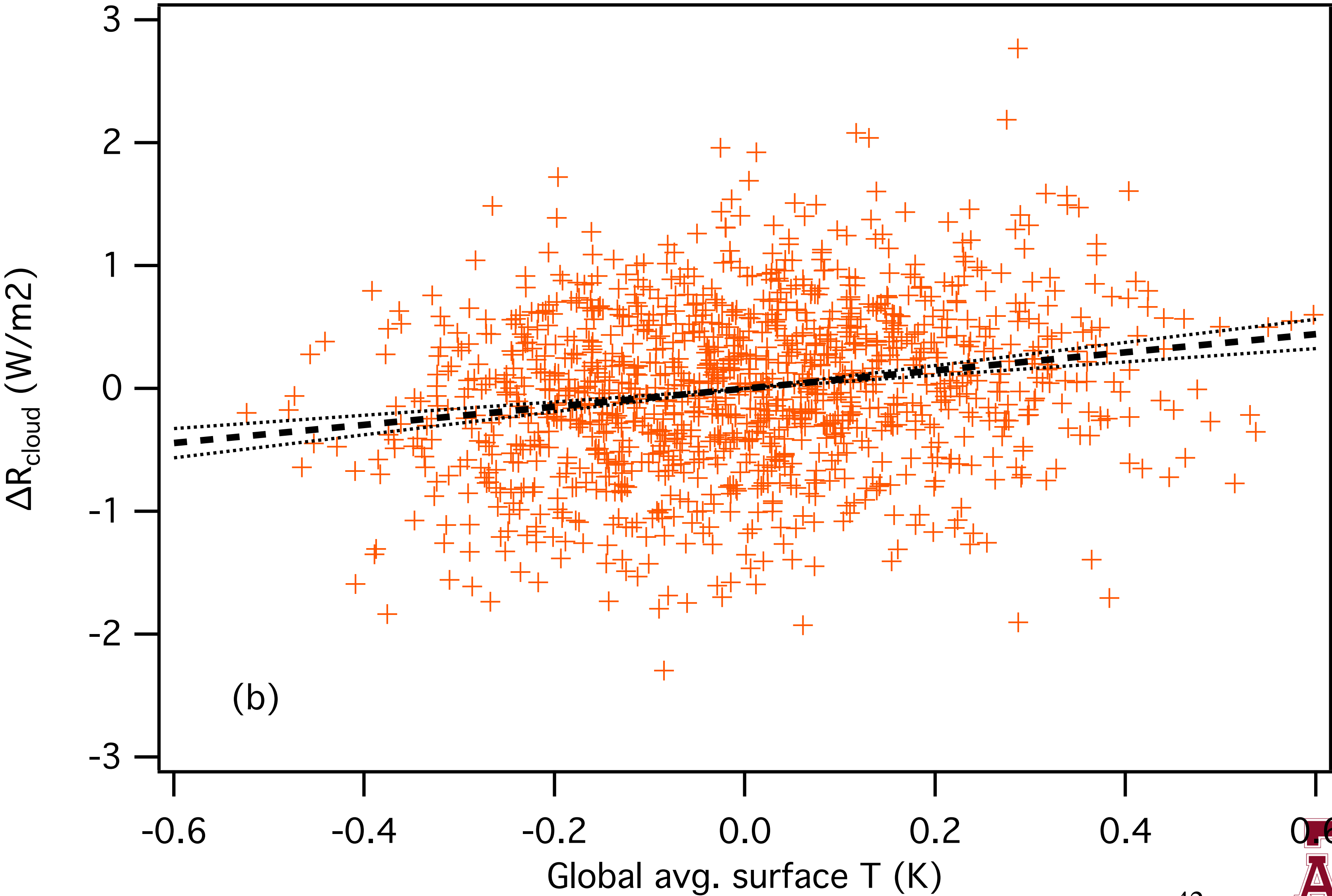


A few lessons

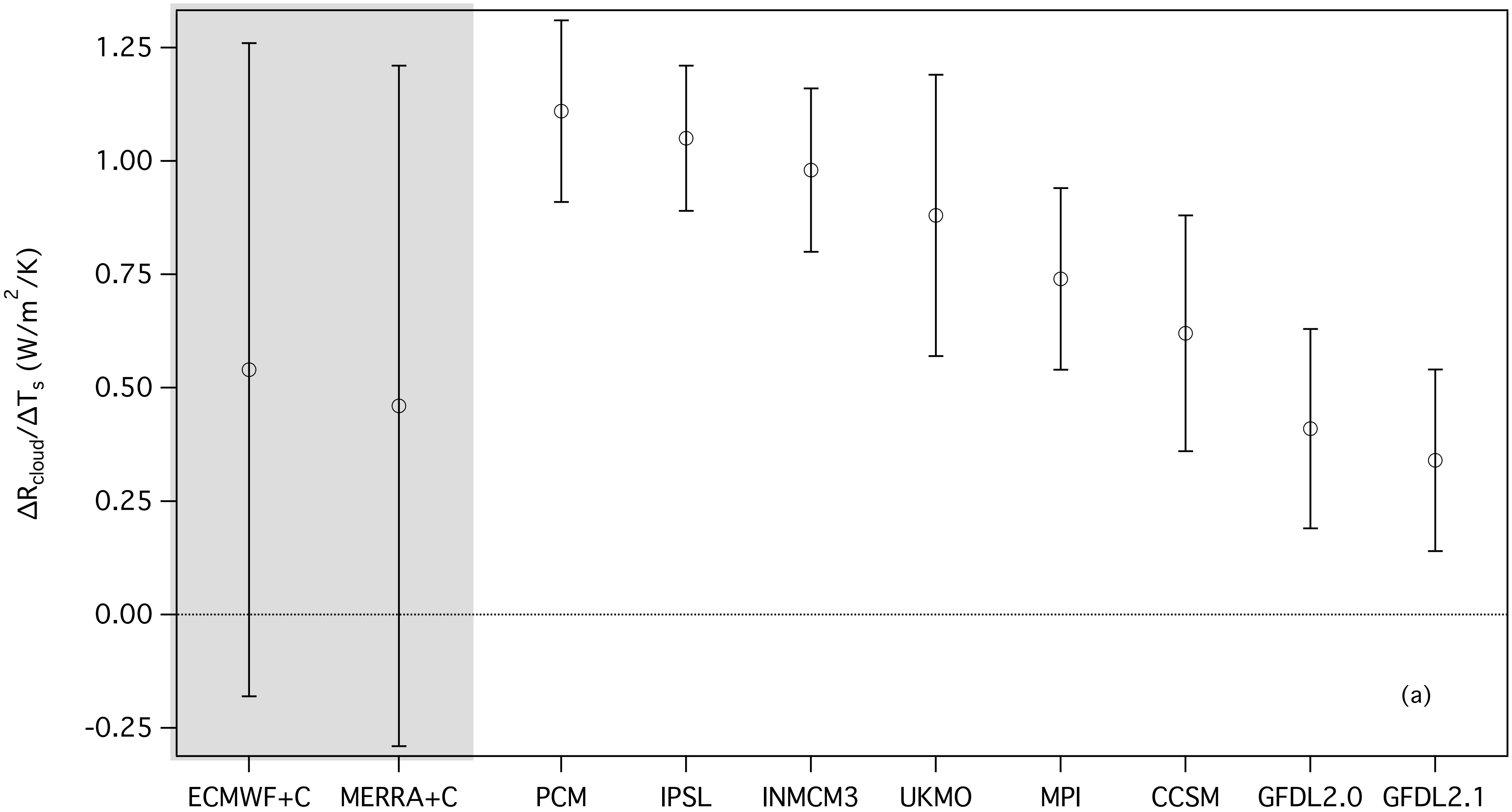
- This scatter is real
- Another few years of data will not help
- We must study modes of cloud variations that are NOT related to surface T variations
  - e.g., MJO
- Models correctly simulate the scatter

MPI ECHAM5

$\lambda_{cloud} = 0.74 \pm 0.20$ W/m²/K; $r^2 = 4\%$



short-term cloud feedback intercomparison



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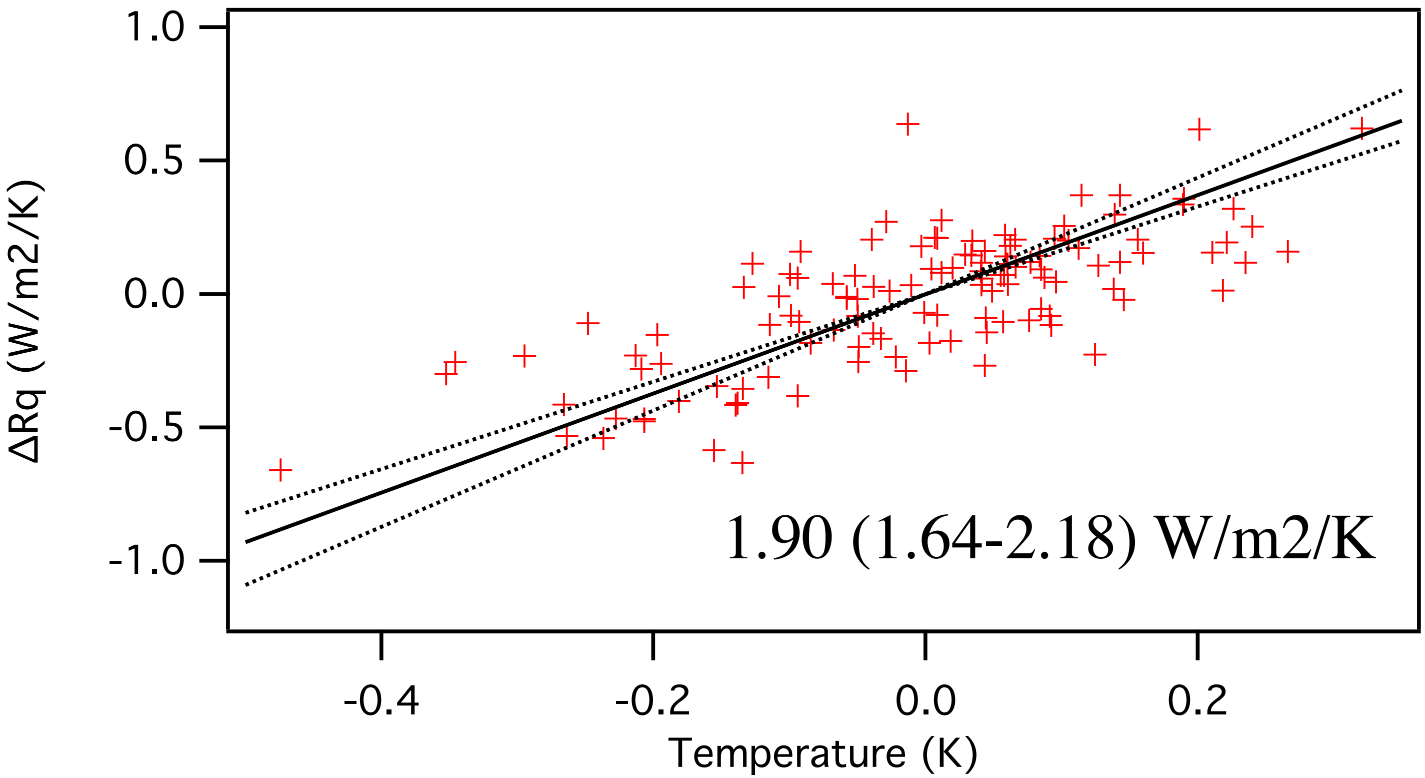
- This work was supported by NASA grant NNX08AR27G to TAMU

ECMWF-interim reanalysis
3/2000-2/2010

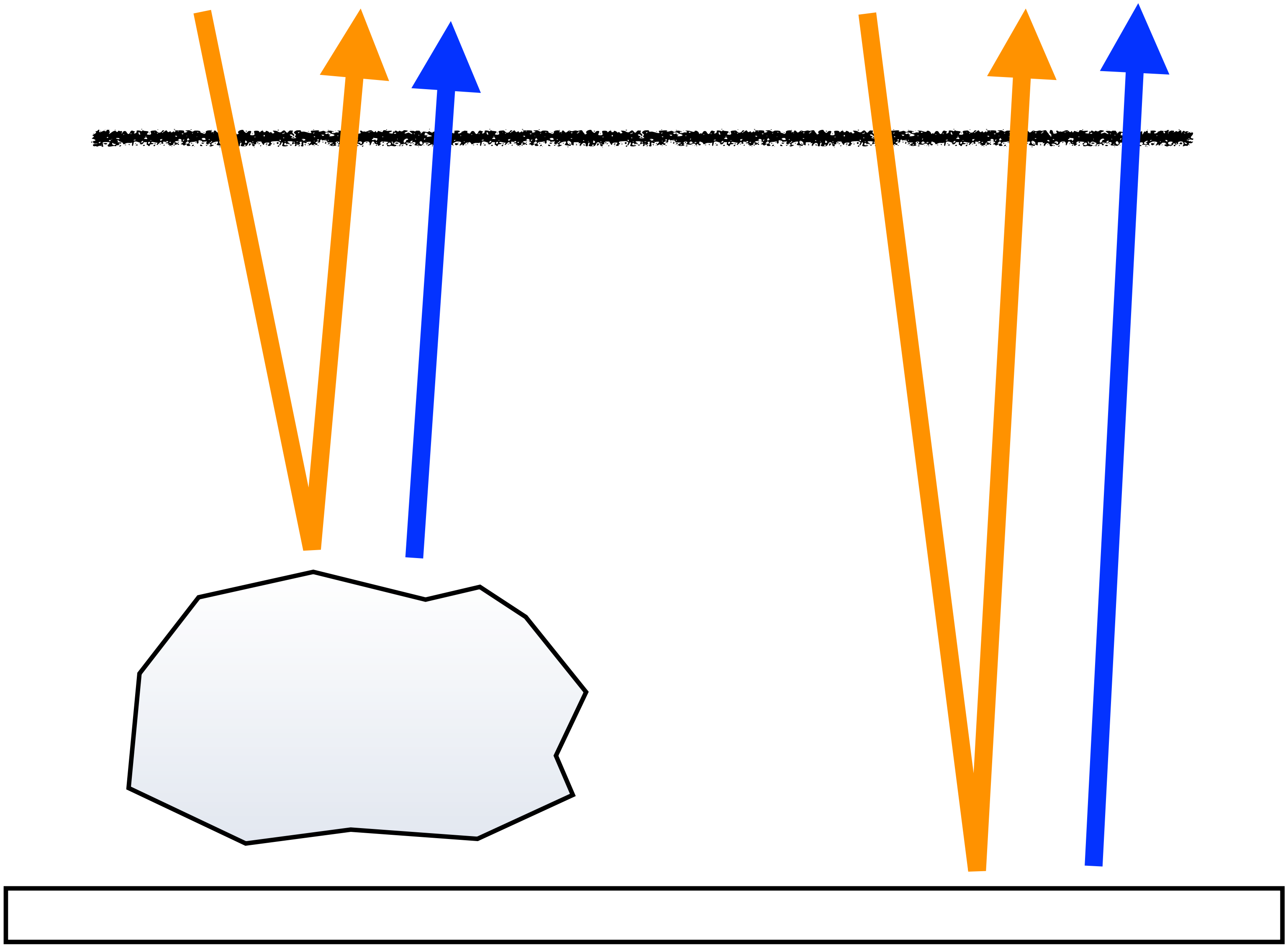


Tropical avg. T

Model	Total		Long wave		Short wave		Long-term cloud feedback	Climate sensitivity
	Cloud feedback	r^2	Cloud feedback	r^2	Cloud feedback	r^2		
FGOALS-g1.0	1.24±0.16	28%	0.92±0.08	48%	0.32±0.15	3%	N/A	2.3
PCM	1.11±0.20	10%	0.52±0.11	7%	0.60±0.21	3%	0.18	2.1
IPSL-CM4	1.05±0.16	12%	1.17±0.13	21%	-0.12±0.14	0.2%	1.06	4.4
INM-CM3.0	0.98±0.18	9%	0.77±0.10	15%	0.21±0.19	0.4%	0.35	2.1
UKMO-HadCM3	0.88±0.31	5%	0.57±0.15	9%	0.31±0.35	0.5%	1.08	3.3
ECHAM/MPI-OM	0.74±0.20	4%	0.97±0.09	27%	-0.23±0.20	0.4%	1.18	3.4
CCSM3	0.62±0.26	2%	0.17±0.12	0.9%	0.45±0.25	1%	0.14	2.7
GFDL-CM2.1	0.34±0.20	0.9%	0.40±0.08	8%	-0.06±0.23	0%	0.81	3.4
GFDL-CM2.0	0.15±0.20	0.2%	-0.63±0.10	11%	0.78±0.21	4%	0.67	2.9
ECMWF-CERES	0.54±0.72	1.9%	0.43±0.45	3.0%	0.12±0.78	0.1%	N/A	N/A
MERRA-CERES	0.46±0.75	1.3%	0.27±0.47	1.2%	0.19±0.76	0.2%	N/A	N/A

$$CRF = R_{all\text{-}sky} - R_{clear\text{-}sky}$$

$$CRF = 0$$



$$CRF = R_{all\text{-}sky} - R_{clear\text{-}sky}$$

$$CRF \neq 0$$